

CONFERENCE PROCEEDINGS

RAND

The Global Course of the Information Revolution: Technological Trends

*Proceedings of an International
Conference*

DISTRIBUTION STATEMENT A

Approved for Public Release
Distribution Unlimited

*Robert H. Anderson, Philip S. Anton,
Steven C. Bankes, Tora K. Bikson,
Jonathan Caulkins, Peter J. Denning,
James A. Dewar, Richard O. Hundley, and
C. Richard Neu*

National Defense Research Institute

Prepared for the National Intelligence Council

DTIC QUALITY INSPECTED 4

20000920 100

The conference papers described in this report were supported by the National Intelligence Council (NIC) and RAND's National Defense Research Institute.

ISBN: 0-8330-2906-1

The RAND conference proceedings series makes it possible to publish conference papers and discussions quickly by forgoing formal review, editing, and reformatting. Proceedings may include materials as diverse as reproductions of briefing charts, talking points, or carefully written scientific papers. Citation and quotation is permitted, but it is advisable to check with authors before citing or quoting because of the informal nature of the material.

RAND is a nonprofit institution that helps improve policy and decisionmaking through research and analysis. RAND® is a registered trademark. RAND's publications do not necessarily reflect the opinions or policies of its research sponsors.

© Copyright 2000 RAND

All rights reserved. No part of this book may be reproduced in any form by any electronic or mechanical means (including photocopying, recording, or information storage and retrieval) without permission in writing from RAND.

Published 2000 by RAND

1700 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138

1200 South Hayes Street, Arlington, VA 22202-5050

RAND URL: <http://www.rand.org/>

To order RAND documents or to obtain additional information, contact Distribution Services: Telephone: (310) 451-7002; Fax: (310) 451-6915; Internet: order@rand.org

CONFERENCE PROCEEDINGS

RAND

The Global Course of the Information Revolution: Technological Trends

*Proceedings of an International
Conference*

*Robert H. Anderson, Philip S. Anton,
Steven C. Bankes, Tora K. Bikson,
Jonathan Caulkins, Peter J. Denning,
James A. Dewar, Richard O. Hundley, and
C. Richard Neu*

National Defense Research Institute

CF-157-NIC

Preface

The National Intelligence Council (NIC) is undertaking a systematic research and development program on broad, crosscutting issues for the next millennium; this constitutes the DCI's Strategic Estimates Program. One of these strategic estimates focuses on developing a better understanding of the future course of the information revolution throughout the world over the next 10-20 years.

The NIC has asked RAND to take the lead in this effort to chart the future course of the information revolution. As the first step in a multi-year program of research, RAND convened an international conference in Washington DC in November 1999, focusing on the political/governmental, business/financial, and social/cultural dimensions of the information revolution, as they are unfolding in different areas of the world. The proceedings of that conference were published in Hundley et al (2000).

The second conference in this series was held in Pittsburgh PA in May 2000. That conference focused on technology trends in the information revolution. This report contains the proceedings of that second conference.

This research is sponsored by the National Intelligence Council, and monitored by the National Intelligence Officer (NIO) for Science and Technology. It is being conducted by the Acquisition and Technology Policy Center of RAND's National Defense Research Institute (NDRI). NDRI is a federally funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, the defense agencies, and the unified commands.

Contents

Preface	iii
Figures	vii
Tables	ix
Summary	xi
Acknowledgments.....	xxi
Acronyms	xxiii
1. Introduction.....	1
2. Future Visions.....	7
3. Observations on Future Trends	17
4. Technology Trends and Artifacts.....	23
5. Services	33
6. Markets	51
7. Beyond Cyberspace	57
8. Some Observations on the Group Reports.....	73
9. Concluding Remarks	77
10. What Comes Next	81
Appendices	
A. Predicting the Unpredictable: Technology and Society	83
B. Conference Participants	95
C. Conference Agenda.....	99
Bibliography	103

Figures

Figure 1.1 Participants in Conference, by Affiliation	2
Figure 5.1 A Framework for Information Technology and Services	36
Figure 6.1 Developments Depend on Separate Markets for Invention and Innovation	55
Figure 6.2 The Interplay of Innovation and Invention Over Time	56

Tables

Table S.1 Examples of Possible Regional Market Drivers and Limiters xvii

Table 6.1 Examples of Possible Regional Market Drivers and Limiters 54

Summary

RAND has undertaken a three-year effort, sponsored by the National Intelligence Council, to study some of the key changes expected worldwide as a result of the continuing information revolution. A first conference in a series was held November 16-18, 1999 in Washington, DC, concentrating on potential political, economic, and social consequences of this revolution, with special attention focused on differential impacts possible in differing countries, regions, and cultures of the world.

A second conference in this series, reported on here, was held May 10-12, 2000, in Pittsburgh PA. It concentrated on technical trends in the information revolution, focusing in particular on the resulting new artifacts and services that might become widespread during the next 20 years, thereby affecting individuals, organizations, nations, and cultures worldwide.

In one sense, it is easy to “predict” the future, at least over the next 15-20 years: computing will get faster and cheaper, communication bandwidth will increase, interesting new devices (beyond cellphones and handheld personal information managers, or perhaps a merging of the two) will emerge. And so on. And yet, many previous attempts to forecast future technology developments have been woefully lacking, if not just plain wrong. Twenty years ago, circa 1980, essentially no one predicted the explosive development of the World Wide Web – indeed, although a precursor of the Internet was a fairly robust technology, there was no HTML, nothing like today’s “chat rooms,” and no 500-megahertz multi-gigabyte laptop computers, or cell phones. So the “faster / cheaper / smaller” mantra only hints at future developments, it certainly doesn’t predict them. Conversely, projections often appear naively optimistic in retrospect. (As one participant put it, “If it’s 2000 already, why doesn’t my car fly?”)

This conference attempted to get beyond Moore’s Law (an expected doubling of the density of integrated circuits on a silicon chip every 18 months or so), to ask about specific artifacts, devices, and services that might be developed, with attention to those likely to have differential impacts on various countries, regions, and cultures of the world. The conference was designed to illuminate the assumptions underlying various predictions and estimates, so that these could be examined for mutual consistency and likelihood.

We structured the conference in part by distinguishing among developments in technology, artifacts, and services.¹ We view *technology* as the idea or intellectual property behind an artifact or product that embodies it, such as wireless communication technology *per se*. An *artifact* is a device (such as a cellular telephone) embodying one or more technologies. *Services*, similarly, result from the application of technology, but in the form of capabilities offered to users, usually in a form resulting from storage, access, and manipulation of information. A website that helps you locate the nearest CD music store might be such a service.

Below we list the major topic areas and findings resulting from the conference deliberations, under the headings of technology, artifact, and service developments. We indicate for each the report sections in which more information is available on these subjects.

Some clear technology developments

It is widely believed that the exponential growth in computing power that has been seen for decades now will continue for at least another 10-15 years, reaching the limits of silicon technology by about 2015. That trend underlies many of the other developments that are expected.

There will be a convergence of voice and data communications, and a quantum jump in bandwidth during the next two decades. These developments will be characterized in first-world economies by:

- Seamless data, voice, video sharing
- Universal connectivity
- Application convergence through Internet Protocol (IP)
- Widespread wideband wireless
- Optical, multiwave lines and switches, allowing bandwidths of thousands of gigabits/sec

A white paper on communication technology developments provided to conference participants by Professor David Farber, Chief Technologist, Federal Communications Commission, is included in this report (Appendix A).

Machine-accessible common-sense knowledge will become available to various computer applications, especially in bounded domains of discourse. It will aid a variety of applications, most particularly on the World Wide Web – such as

¹ A similar distinction, but one varying in some aspects, was described in the proceedings of the first conference in this series. See Hundley (2000), section 10.

helping to provide “sensible” answers to browser queries and other forms of user-computer dialog.

Machine translation (MT) among key natural languages is a long-sought goal. Its availability, for example, would allow the informational riches of the Web – currently predominantly in English – to be accessed by persons whose only language is Arabic, Japanese, Chinese, or Spanish (for example). The general MT problem is unlikely to be “solved” in the next 20 years, but it was stated that “you can have any two of the following three desiderata: high quality, general purpose, fully automatic.” For many purposes and limited domains of discourse, this will be good enough for useful applications.

There are very strong synergies developing between bio-, nano-, and material technologies. Beyond semiconductors, on-chip integration of logic and other components will likely include chemical sensors and components, electro-optical devices, and biological components as well as microelectromechanical systems (MEMS). The results, especially for sensor technology – and when combined with wireless communication developments – will be revolutionary, with an expected cornucopia of new devices and applications.

Future technology developments are discussed in more detail in Sections 2 and 3 of this report.

Some clear artifact developments

Given developments in underlying computing and communication technologies, we expect to see a multitude of diverse, powerful, inexpensive sensors and other devices capable of (limited-distance) wireless communication. Among them are tiny video cameras, MEMS microphones, accelerometers, gyros, GPS receivers providing location information, smell sensors, food spoilage sensors, biosensors, and polymer-based sensors. These devices will provide vastly increased coupling between the physical world and the cyber world, allowing information systems to react much more comprehensively to (changes in) their environment.

Computing and information systems will become much more ubiquitous, with convergence of wireless telephones, personal digital assistants (PDAs), radio, voice and e-mail messaging, smart home appliances, etc. Precursor devices in this trend are the Palm VII and the RIM BlackBerry. Developments in such small, portable, personal devices along with sensing technology will make wearable computers increasingly important informational aids. Aiding in these developments will be protocols such as WAP (wireless application protocol) and the Bluetooth radio protocol for short-range wireless communication.

Section 4 of this report provides further discussion of developments in informational artifacts.

Some clear services developments

There is a major shift underway in business emphasis, from products to services. Increasingly, businesses see specific products as elements or components of a broader service that the firm provides to customers. Information technologies are central to this new business model.

Because of the conference's interest in artifacts and services with the potential to have major effects on differing regions and cultures worldwide, there was considerable interest in the state-of-the-art of machine translation of human languages, provided as a service on the Internet and Web. This technology, along with automatic voice recognition, could have profound effects in making information for education and entertainment available around the world. The emphasis was not on perfection in these services, but rather on the availability of "good enough" translation and voice recognition to allow access to Web resources by speakers of a variety of languages, and on freeing the user from keyboard-dependent interfaces through voice recognition. With this combination of technologies, one can imagine kiosks at which a question can be voiced, and the riches of the Internet used to provide a spoken or displayed answer. It may even be reasonable to imagine that kiosk containing a small satellite dish by which Internet and other informational services are accessed, and solar cells and auxiliary batteries by which it is powered as a self-sufficient informational platform.

Services available from such a kiosk might – at least initially – be tailored to certain specialized areas, such as farming, weather reports, market prices for agricultural products, and so on. In that manner, the complexities of translation and voice recognition might be "good enough" for effective usage. (Conference attendees were told, for example, of high-quality, automatic language translation now being performed for the limited domain of Caterpillar tractor manuals.)

There was discussion of robust, global information utilities serving a wide variety of needs. As is increasingly the case, entertainment will likely lead the way, with business-to-business (B2B) e-commerce as a strong second force. As these information utilities grow, they will become backbones supporting increased lifelong learning and specialized training.

The breakout group on future IT services concentrated on four areas of "final" (end-user-related) services: health care, education, entertainment, and supply-

chain management. These are considered to be selected examples of services areas, certainly not a definitive list.

Health care services will increasingly be influenced by "telemedicine," in which some or all of the services will be IT-mediated. The opportunity to access information and actual care from a vastly expanded set of providers will confront both patients and health-care professionals with a bewildering array of choices. This in turn may generate new dynamic brokering services. Although telemedicine is likely to increase the gap between rich and poor societies (e.g., because high, reliable bandwidth is often required), some benefits will accrue to poorer countries, for example from their improved access to information and training. The group felt that such developments as a "smart stretcher" being investigated by the U.S. military might prove important to countries short of trained medical personnel.

In educational services, the greatest impact of the continuing information revolution is likely to be in lifetime learning and specialized training. Other important changes will occur in post-graduate education. It was felt that university undergraduate studies and K-12 education will be less affected over this time period due to a variety of social, political, and other factors, but may be dramatically affected somewhat later.

Entertainment will continue to be a powerful driver of IT developments in the next 15-20 years. Among the artifacts and services expected to play a large role are:

- Multi-person computer-based games
- Web-mediated physical activity, such as interactive games requiring strenuous physical responses
- Ubiquitous web-cams providing entertainment, communication (improved interpersonal interaction at a distance) and intrusive surveillance
- Interactions with people of different cultures, aided by translation programs
- The ability to view athletic events from almost any vantage point
- Video glasses that place images directly before a viewer's eyes
- E-books.

IT-enabled supply-chain management and the general control of production processes were considered as drastically reducing the advantages that accrue to cheap labor, possibly ending the flight of manufacturing to the developing world. The key to highly effective production control services may be in devising better ways to allow humans to visualize and to understand intuitively the workings of very complex systems.

The above examples of IT-enabled services depend on a number of enabling services. Ones considered especially important were security, validation, payment, and dynamic brokerage. The importance of secure Internet and Web services is clear. “Validation” is closely related: it refers to the importance of being able to trust that you are communicating with an intended party, and that the information received and transmitted is to be trusted.

Payment schemes such as “micropayments” will be increasingly important in allowing e-commerce services to charge small amounts (less than the cost of processing a credit card payment) for small services performed, such as reading a document, or downloading a small file. “Dynamic brokerage” refers to a decentralized capability for matching highly specific requests from customers for packages of services with suitable offers of these services from a wide range of suppliers. This requires creating of a standard vocabulary for articulating requests for services, and for describing services offered.

Further discussion of services is provided in section 5 of this report.

Markets

Much of the discussion at the conference was deliberately related to “technology push.” Yet participants understood that markets play a critical role in determining which of the *possible* artifacts and services become *actual* and widespread. The group discussing market factors created lists of “filters” that new developments must pass through in order to become actualized. Such filters include: the availability of supporting infrastructure; market demand factors like ease of use, entertainment value, and affordability; and availability of funding.

It was also noted that market criteria play differing roles in various regions of the world. The group created the chart (Table S.1) as showing examples of market criteria by region, although its content is not based on any serious analysis. It is meant as a framework that might be filled in more accurately and carefully by regional and technology experts working together.

Table S.1: Examples of Possible Regional Market Drivers and Limiters

	Drivers	Limiters
North America	time savings improves health	backward compatibility
Europe	educational value time savings improves health	social concerns; backward compatibility
North Asia	fashion, image educational value	government policy; backward compatibility
Mideast		social concerns
South(East) Asia	creates expertise empowerment educational value	lack of capital, infrastructure, and human expertise
Africa	creates expertise empowerment fulfills basic life needs	lack of capital, infrastructure, and human expertise
Latin America	creates expertise	lack of capital, infrastructure, and human expertise

This group's discussion also distinguished between the market for invention, and that for innovation. Each was characterized as relatively distinct from the other. How IT-related products emerge from basic research, through revolutionary change, into breakthrough products, and gradual evolutionary change – or don't do so successfully – depends to a large extent on the "market" for invention, and for innovation, within a society.

Further discussion of market factors affecting the development of IT artifacts and services is in section 6 of this report.

"Beyond cyberspace"

One breakout session labeled its topic "beyond cyberspace." This label was meant to cover such subjects as: What will happen when information technology is ubiquitous and permeates social space? What will happen when IT becomes part of the background rather than a locus of emerging foreground trends?

The discussion of this group focused on four domains of human concern: work; political processes and governance; education; and crime.

It is clear that manual labor is increasingly being replaced by knowledge work. Among the effects noted were that, "We've turned the Taylor model on its head. Knowledge workers know more than the managers do now, and knowledge workers have so much mobility that they control the viability of the corporation." The group foresaw increasing use of "collaborative networks" across different physical environments and time zones. It is possible that there will be more "componentization" of software systems and knowledge-based jobs, making it possible to issue bids for all kinds of work. The main task left to the corporation would be to assemble the results as they came back from bidders. But would work then become less meaningful? If so, with what consequences?

Another work-related effect of the IT revolution discussed was the reorganization of industries, especially focused on a trend toward disintermediation of work, with the likely result that new classes of intermediaries will emerge from this restructuring. There are also many issues brought to the fore by IT developments involving the migration of workers across national boundaries. Some mass migrations, especially of knowledge workers, are possible – with unclear effects on the "steady state" of the world.

The discussion of political processes and governance ranged over possible challenges to national sovereignty, government's services to its citizens, and electoral politics. It was felt – as others have noted – that internationalization of markets and the fluidity of the labor force further contribute to the marginalization of the nation state. In addition, nation states increasingly share *de facto* power with large multinational corporations and nongovernmental organizations.

Among various trends involving government, it appears that regulatory agencies are especially at risk of not keeping pace with developments, given IT-enabled fluidity and fast-paced changes in markets and financial systems. In addition, some traditional government services (e.g., the postal service) are competing with private services (e.g., FedEx, UPS, e-mail providers).

Ubiquitous information technology will increase the pressure for "e-voting." The rationale for representative government will be challenged by advocates for direct democracy. One participant characterized e-voting as the "death of deliberation." A number of "micro-elections" on various special measures and single-issue initiatives may in fact increase voter apathy. There are many social and political factors to be considered in this arena.

This group also discussed IT and education, as did some other groups. The basic conclusions were similar to others': distance learning and post-secondary education would likely be most affected, and increase in the corporate education

sector would be evident. Participants also believed that technical advances – such as those mentioned above in language translation and voice recognition – may well yield small, inexpensive IT devices that could be distributed on a one-per-child basis to spread appropriate education throughout developing countries.

The topic of IT-affected changes in crime was briefly discussed. Ubiquitous IT will significantly reduce physical crime, both because of greatly increased surveillance from inexpensive sensors, and due to DNA tracing and other advanced analytic techniques. An unintended consequence may well be the shifting of crime to the IT world, where new kinds of extortion and digital retribution may become possible. The cat-and-mouse game between cybercrime and cyberforensics will continue.

Other societal effects of ubiquitous IT technology are discussed in section 7.

Some tensions arising from these developments

A number of individual and societal tensions arise from the developments outlined above.

As one example, participants believed that ultra high-speed all-optical communication networks will be a highly disruptive technology. It is possible that many present-day leaders in computer and communications industries will be threatened with extinction.

There are major battles to be waged between advocates of “open” versus “closed” worlds of protocols and standards. It is unclear where the balance will be found.

Among the many social tensions are increasing threats to intellectual property rights, for example from new business models such as that exemplified by Napster and Gnutella. Threats to individual privacy will increase. And it is likely that many of the new IT artifacts and services will in fact, as is often the case, primarily benefit those with the resources to obtain and exploit them.

What comes next?

This document reports on the second of a planned series of conferences. The conferences to date have considered some political, economic, and social consequences of the information revolution, and key technical trends. Among the topics requiring further work are: better, parameterized models of the

information revolution, and discussion of which models are appropriate for which countries and regions of the world; more study of the information revolution in Latin America; better quantitative projections of future IT penetration throughout the world; and a better understanding of "proximity" in the information age – an understanding of which societal activities will cluster geographically and which will disperse.

We also anticipate holding two more major international conferences, preferably in Europe and Asia, to expose and vet our results before a wider international audience, and thereby to broaden and deepen our models of the future course of the information revolution throughout the world.

Acknowledgments

The results presented here are due to the collaborative efforts of all of the conference participants, who are listed in Appendix A. They all deserve a major vote of thanks.

Special thanks are due to the individuals who presented prepared talks at the conference: Dr. Philip Anton, Dr. Joel Birnbaum, Dr. William Caelli, Dr. Colin Crook, Dr. David Farber, Dr. Robert Frederking, Dr. Erol Gelenbe, Mr. Eric Harslem, Dr. Richard Hundley, Mr. James Kearns, and Dr. Douglas Lenat.

We also thank the other individuals who served as leaders of the breakout groups: Dr. William Caelli, Dr. Colin Crook, and Ms. Lily Wu.

The following RAND personnel acted as rapporteurs: Dr. Steven Bankes, Dr. Tora Bikson, Dr. Jonathan Caulkins, Dr. James Dewar, Dr. Richard Hundley, Dr. C. Richard Neu. Without their efforts this report could not have been completed.

Debra Patterson of RAND's Pittsburgh office provided highly competent on-site support. We also appreciate the efforts of Professors Raj Reddy and V.S. Arunachalam of CMU in arranging technology demonstrations of research underway there in robotics, language translation, and speech understanding for the edification and enjoyment of the conference participants.

Finally, thanks are also due to Dr. Lawrence Gershwin, the National Intelligence Officer for Science and Technology, whose vision and support of this conference were vital to its success.

Robert H. Anderson, Peter J. Denning
Conference Co-Chairs

Acronyms

AAAS	American Association for the Advancement of Science
ABS	automated braking system
AMD	Advanced Micro Devices, Inc.
AOL	America Online
ACM	Association for Computing Machinery
ANSI	American National Standards Institute
CIO	chief information officer
CMU	Carnegie Mellon University
CPU	central processing unit
DARPA	Defense Advanced Research Projects Agency
DCI	Director of Central Intelligence
DNA	deoxyribonucleic acid
FAO	Food and Agriculture Organization (United Nations)
FCC	Federal Communications Commission
FDA	Food & Drug Administration
FFRDC	Federally Financed Research and Development Center
GHz	gigahertz
GIS	geographic information system
GMU	George Mason University
GPS	global positioning system
GSM	Global System for Mobile Communications (previously Groupe Spécial Mobile)
HP	Hewlett-Packard Company
IEEE	The Institute of Electrical and Electronics Engineers
IEM	international electronic marketplace
IMF	International Monetary Fund
IP	Internet protocol; intellectual property
ISDN	integrated services digital network
ISO	International Standards Organization
ISP	Internet service provider
IT	information technology
K-12	kindergarten through 12 th grade
LEO	low earth orbit (satellites)
mA	milliamps
MEMS	microelectromechanical systems
MIPS	millions of instructions per second

MT	machine translation
NAFTA	North American Free Trade Agreement
NDRI	RAND's National Defense Research Institute, an FFRDC
NGO	non-governmental organization
NIC	National Intelligence Council
NIO	National Intelligence Officer
NSF	National Science Foundation
PC	personal computer
PEPC	privacy enhanced personal computer
PDA	personal digital assistant
QUT	Queensland University of Technology (Australia)
RAM	random-access memory
RIM	Research in Motion, Ltd.
SEC	Securities and Exchange Commission
SOHO	small office / home office
UCF	University of Central Florida
UCSB	University of California at Santa Barbara
UNDP	United Nations Development Programme
UNICEF	United Nations International Children's Emergency Fund
VLSI	very large scale integration
WAP	wireless application protocol
WIPO	World Intellectual Property Organization
WTO	World Trade Organization
xDSL	x digital subscriber line ($x=A$ [asynchronous], ...)

1. Introduction

Conference Co-Chairs:
Robert H. Anderson, Peter J. Denning

Through the Information Revolution Initiative of the US National Intelligence Council's (NIC's) Strategic Estimate Program, the US Government has undertaken a major study to chart the most likely course of the information revolution globally by 2020. The study is to encompass technical, business, financial, geopolitical, social, cultural, and national security issues. The study will take a total of three years and will draw heavily on several conferences. The results of this study will form a foundation that is likely to influence future research and various areas of government policy.

The RAND Corporation, because of its expertise in strategic planning, was tasked by the NIC to assist it in this initiative. RAND launched the study in November 1999 with a conference to assess trends in business, finance, governments, societies, and cultures driven by information technologies in various nations and regions of the world. The conference was attended by a broad cross-section of intellectual leaders from North America, Europe, and the Asia Pacific region. The main objectives of the conference were to: (1) Map out, region by region, key forces that will shape the information revolution, (2) Illustrate and explain differences between trends in the different regions, and (3) offer scenarios of information-technological futures for the regions. The proceedings of this conference (Hundley et al, 2000) have been published and were sent to participants in the conference being reported on here as background reading.

Objective of This "Technological Trends" Conference

On May 10-12, 2000, a second conference in this series was held at the University Club, Pittsburgh PA, with associated technology demonstrations and a reception at Carnegie Mellon University. The purpose of that conference, the subject of these proceedings, was to study the technology "drivers" of the information revolution. It sought to assess the effects of technologies already in use and to

speculate on the effects of new technologies that are likely to be put into practice by 2020. Forty-two invited participants attended, among whom were a number of information technology leaders from academia, industry and government. A breakdown of participants is shown in Fig. 1.1.

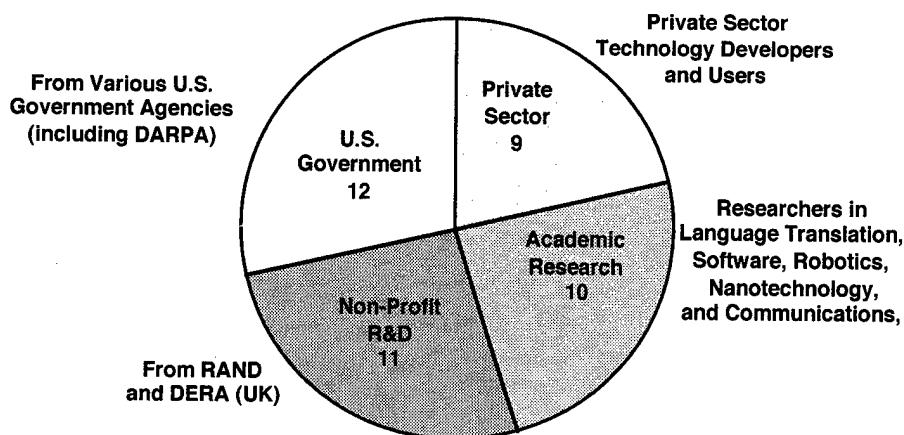


Figure 1..1 – Participants in Conference, by Affiliation

The conference addressed the important question of *how* IT systems will be *used* in the next twenty years. The notion of being used or practiced is very important for our purposes. Technologies that offer little value to people will not be used, no matter how interesting they are to their inventors. The most useful technologies are those that help solve major business, economic, communication, financial, and even cultural problems. The time has now passed when technologists can simply invent what they think will be useful. This is why the first conference -- to clarify the various contexts of use for information technology -- was held before this technology analysis conference.

Considerations on Attempting to Predict Future Developments

Predicting future actions of people is a risky exercise. Even so, some efforts have demonstrated competence at this and we can learn from them. We have sought to organize this conference to draw on competent prediction practice.

Methods of prediction, such as they are, fall into three broad categories:

- **Trend Extrapolation**, which examines the consequences of current realities; it works best when limited to 5-15 years in the future and breaks down for

longer projections because it does not account for how people react to the advancing trend.

- **"Reading the Clearing,"** which looks at the space of human practices -- historical, cultural, social, and technological. "Clearing" is a metaphor for a space in the forest, a space in which motion and action are possible; actions outside the limits of the "clearing" are not possible. This perspective reveals that technologies do not "drive" social change, but rather interact with social concerns, interests, and moods, producing changes in people's practices and ways of doing things. This perspective is more successful than any other method for projections beyond 20 years.²
- **Wishful Thinking,** which expresses hopes, fears or expectations about the future but offers little grounding for these opinions; it is perhaps the most popular of the three methods, and the least successful.

In 1893, as part of the Fourth Columbian Exposition, the Newspaper Guild invited 74 leaders of the day, from all walks of life, to speculate what the world would be like 100 years hence. Their essays were published in the newspapers in the weeks preceding the Exposition. In 1993, Historian Dave Walter resurrected these essays and collected them into a book called *Today Then*. What is most striking about this collection is how few of the predictions actually came to pass. Only 5 of the 74 authors discussed futures that resemble the world as we know it today. The others confidently predicted that technology would eliminate the distinctions between haves and have-nots, reduce postage to one cent, eliminate most crime, give people more time to advance their education, reduce taxation, and limit the scope of government. They predicted that the United States would encompass all of North America in about 60 states, that railroads would be the primary means of transportation, that pneumatic tubes would move people around cities and be used for transcontinental mail transport, and that aircraft would be limited to military uses. Only a few foresaw universal electric power and telephone, a communication system resembling the Internet, or a doubling of expected lifespan. No one foresaw world wars, the Interstate highway system, genetic engineering, mass state education, broadcast radio or TV, or the computer.

² Herbert Dreyfus derived the metaphor "the clearing" from the work of the philosopher Martin Heidegger (Dreyfus, 1990). The "clearing" is the space of possible human action. Fernando Flores coined the metaphor "reading the world" to denote understanding how the world is moving (Spinoza, Dreyfus, and Flores, 1997). One of us (Denning) put these two slightly different contexts (world and clearing) into juxtaposition. Peter Drucker has used this approach in much of his recent work, but without giving it this name. (See, for example, Drucker, 1989.)

Looking back at the predictions of those leaders of yesteryear, we learn more about the kinds of observers they were than we do about our own day. We ask what were the assumptions they made that influenced their conclusions. We wonder what an observer 50 or 100 years from now will think of the predictions that come from this conference. We see in retrospect that most of their predictions were wishful thinking. A few of their predictions were trend extrapolations, all leading to the wrong conclusions. The five who "got it right" were all clearing-readers.

The task before us at this conference was to extrapolate trends over the next 15 years, which is about the empirical limit for extrapolations, and to read the clearing for predictions beyond that. We most definitely wanted to avoid wishful thinking. Consequently there is a lot of emphasis on understanding all the assumptions behind every forecast.

This conference used the ACM 97 Conference as a point of departure. See Denning and Metcalfe (1997) and Denning (1999) for collections of essays that summarize the visionary statements of industry leaders at that time. The ACM97 conference was a set of presentations, but there was no attempt to evaluate the credibility of each speculation or to reveal the key assumptions made by each speaker. We tried in this present conference to meet these two additional objectives.

Scope of Conference

The objective of the conference was to describe and understand -- to the extent possible -- the key developments in information-related technology -- artifacts, systems, and usage -- that could occur during the next 20 years. We focused on developments that might have major economic, social, cultural, or political impact, and attempted to take explicit account of possible differential impacts in different regions of the world. Accordingly, the conference concentrated on the topics summarized below as being of particular interest.

- Technology, artifacts, and developments in usage of information technology that facilitate access by those currently not "wired," such as those that avoid (or overcome) requirements for specialized training -- e.g., interfaces that do not depend on keyboard skills.
- Technologies and practices that remove (or overcome) language barriers.
- Technologies and practices that could accelerate the e-commerce paradigm and possibly lead to new business paradigms.

- Technologies and practices that could lead to new paradigms in education, medicine and health care, entertainment, and other societal areas.

(Note: Entertainment is of particular interest because it is a medium through which social, political, and cultural values are transferred from one nation or generation to another.)

- Technologies and practices that couple cyberspace and physical space.
- Technologies and practices that favor new computing paradigms -- e.g., quantum computing, DNA-based computing, etc. What is the likelihood of any of these technologies being available by 2020? What would favor them? Inhibit them?

The agenda for the conference is shown in Appendix C. A list of participants and their affiliations is provided in Appendix B.

The Structure of This Report

The remainder of this report is organized as follows. Sections 2 and 3 summarize a set of "future visions" provided to an initial plenary session by several speakers in prepared remarks, and comments by a panel of observers reacting to these presentations and the assumptions underlying them.

The conference used four breakout sessions to explore various topics in more detail. The topic categories decided upon within the conference itself were:

- Technology trends and artifacts
- Services
- Markets
- Beyond cyberspace

(The last of these categories requires some explanation: Its charter was to explore the question: "What happens when information technology (IT) is ubiquitous – when cyberspace permeates social space?")

Sections 4-7 report on the deliberations and findings of these four breakout sessions.

Section 8 contains some comments on the results of the breakout sessions by another panel of observers, again attempting to probe behind the findings to elucidate underlying assumptions, and to highlight possible missing topics and issues that weren't explored.

Section 9 presents some concluding remarks on the technology developments in the next 15-20 years that are likely to be particularly significant due to their broad impact.

Section 10 returns to the broader multi-year project of which this present exercise is a part, and discusses “what comes next” for the project.

In addition to the appendices mentioned above, we provide in Appendix A a white paper sent to conference participants afterward by Dr. David Farber of the University of Pennsylvania and the Federal Communications Commission. It contains succinct but useful commentary expanding on likely directions of the communications revolution and some of their implications.

2. Future Visions

**Speakers: Philip Anton, Joel Birnbaum,
William Caelli, Colin Crook, David Farber,
Robert Frederking, Erol Gelenbe, Eric Harslem,
James Kearns, Douglas Lenat**

Rapporteur: Steven Bankes

A set of distinguished speakers provided an initial plenary session of the conference with brief prepared remarks on likely future developments over the next 10-20 years in their respective fields of expertise. The purpose of this session was to provide participants a common set of visions, as a form of raw material for the later deliberations. We summarize key points from these presentations here. Many of these developments and their implications are revisited in more depth in the individual breakout sessions documented in sections 4-7, below.

Technologies and Artifacts

Information and communication technologies, and the products developed from them, are now a major economic force. The trade surplus for the U.S. in information products is 10% of the U.S. trade deficit and growing rapidly.

In deliberations about future developments, it is important to distinguish between underlying *technologies*, and the *artifacts* and *services* derived from them. Current jargon often confuses these concepts. Artifacts and services are the result of one or more technologies, and connect directly to end users. It is much easier to predict advances in technology than to predict the artifacts and services that will result from that technology (and its combination with others). For example, a forecast of IT made 20 years ago in IEEE Computer magazine got the technology performance about right, but missed all the major innovations in artifacts. Similarly, given an artifact, predicting the changes in social usage resulting from the deployment of that artifact can also be very difficult. Thus, in navigating our views of the future, it is important to maintain a distinction

between enabling technology, artifacts and services that may be built using such technology, and the social changes that could result from using anticipated artifacts and services.

Communications Technology

It is very hard to predict the course of the next 20 years in communications technology, but given what we know, the following comments characterize our current expectations. (For a more extended, thoughtful essay on this important subject, see the white paper in Appendix A.)

Optical communication systems

The biggest technical development is likely to be in optical systems. We expect to see commercially available optical switches within the next 4-5 years, implying that end-to-end pure optical systems will be a reality within the timeframe being considered by this conference. Combined with other innovations such as multiwave technology (in which multiple wavelengths are used to carry multiple signals on a single optical fiber), this means that huge improvements in communications bandwidth will be available over the next decade or two.

This development will motivate a rethinking of various other technologies such as the design of computer processors and the Internet Protocol (IP). For example, the ability to route packets optically at very high speeds is questionable, so huge optical bandwidths could motivate a migration away from universal adoption of packet switched protocols for all applications. It may also create the opportunities for much more distributed processor architectures as communications bandwidths may come to rival those of computer backplanes. These developments should be considered *disruptive* to communications and computing industries in the U.S. and throughout the world, in that they will cause some large companies to become obsolete, provide new niches for others, and will force computer system architectures, operating systems, and applications programs to change radically.

The allocation of spectrum bandwidth has become quite antiquated and uneconomical, but is difficult to change. Perhaps we will see spectrum reallocation, but only over a time frame of ten years or longer.

Overall, ground-based optical systems will perhaps be the most revolutionary development during this period, and ultrawideband may be a very important technology exploiting this.

Wireless

The second most important communication technology development over the next 10-20 years will most likely be an explosion in wireless communication. It provides mobility and "everywhere" access. Cellular wireless systems will increasingly be accessed by all-purpose handheld devices combining the operation of a telephone with that of a World Wide Web browser and Personal Information Manager (such as Palm Pilot). These devices will be capable of handling several, or even all, of the different protocols and standards in use worldwide, so that one standard need not be agreed upon worldwide.

Another form of wireless quickly gaining in popularity is based on the "Bluetooth" technology. It allows short-range (e.g., 10 meter) wireless communication based on radio technology. Each device has a unique 48-bit address, and can transmit at one megabit/second, with a likely doubling of bandwidth in the next generation of devices. Such capabilities permit many appliances and devices within a home to "talk" with one another, and to sense the inhabitants (e.g., if they are wearing a Bluetooth-capable badge or carrying an enabled smart card). This will again create explosive new possibilities for networking technology on an intimate scale – within the home or office – with many novel applications, devices, and services to be developed. Many opportunities will be created, enabling entire new businesses to develop and compete worldwide.

"Virtual mailbox" and "cognitive packets" technology

Some common denominators among the cheap and robust communications systems that are likely to appear in this period are the virtual mailbox and networks using what are termed "cognitive packets."

The virtual mailbox is a terminal device or accessible service that allows text to voice and voice to text conversion. It will be possible to listen to voice or text messages, dictate text messages, view pictures, listen to music, and engage in a wide range of media interactions. An artifact may take the form of a portable device used by the more well-to-do, with some type of portable multimedia interface. Or a virtual version may be accessed by everyone through public access points -- some future version of what are now phone booths, public access computer terminals, wireless phones, post offices, or information cafes. Whatever form it takes, the virtual mailbox will have the ability to "chase down" its user (or at least be chased down by him or her), allowing connectivity for sending or receiving messages regardless of location.

These virtual mailboxes will be enabled by cognitive (smart) packet networks that are able to home packets to recipients. It will allow the sender to be informed of delivery or connection. It will support diverse services: letters, voice messages, payments, video clips, instructional material. These cognitive packet networks will put the intelligence in the packets rather than the routers. Packets will route themselves, will learn to achieve goals by exchanging information with other packets, and will allow for high levels of functionality while requiring only very cheap router hardware.

It is likely that communications technology over the next few years will be characterized by the convergence of previously separate media, as the telecom industry, the computer industry, and various media industries combine to create a single infocom industry. This industry will provide seamless data, voice, and video service, with anywhere/anytime connectivity, technology integration, and application convergence.

Software

Machine-accessible common-sense knowledge

At least some of the long anticipated goals of artificial intelligence (AI) will eventually be achieved. Existing systems are not very smart because they have so little knowledge, especially common-sense knowledge that human correspondents take for granted. Handcrafting such knowledge is very labor intensive. Systems can learn from example, but in the absence of contextual knowledge, their rate of learning is similarly very inefficient. One major example of a system addressing this problem is the "Cyc Knowledge Server," under development by Cycorp (www.cycorp.com). The knowledge base underlying this system is being hand constructed with the goal of getting to the cross-over point where it can begin to efficiently learn for itself from human sources such as newspapers.

In designing Cyc, it was necessary to give up on having consistency in its knowledge base. Instead it is designed to be locally consistent, with its global knowledge base consisting of a tapestry of such local contexts.

In general, we expect slow progress, but progress nevertheless, toward the important but elusive goal of having a considerable body of common-sense knowledge available to computational/informational systems.

Machine Translation

Another, somewhat related, technology vital to providing a more natural user interface to computer and information resources is machine translation (MT) between natural languages. Automatic translation between human languages would have important social implications as it becomes more capable. The conference participants were told that the current state of machine translation is captured by the truism that among the three attributes of MT -- high quality, general purpose, and fully automatic -- one can have any two, but not all three at once. This tradeoff comes from the design choice between doing "shallow" translation between sentences of actual languages, or "deep" translation where the source language is translated first to some semantically explicit interlingual representation and from there to the target language. Shallow MT systems -- which tend to use dictionary lookup of words and some simple cues -- tend to be general purpose, inexpensive, and easy to use, but of low quality. Deep systems can achieve higher quality, but are more expensive and require a constrained domain of discourse. An example of a successful deep system is that built for Caterpillar, which can translate such documents as training manuals well but only if they deal with bulldozers and other specific company products.

Expected developments in MT over the next ten years include:

- the ability to conduct Web searches across documents stored in multiple natural languages
- rapid deployment of shallow MT for many "minor" languages as the need arises, and for routine business communications in major languages
- "translating telephones" for minor and limited domains such as travel agencies or help desks.

Over the next 20 years more fundamental improvements may occur in MT, but they would require fundamental breakthroughs that cannot be predicted or expected at this time.

It is important to note that the limiting factor in progress towards MT is software design and knowledge engineering, not hardware. It is therefore not reliable to predict high levels of machine translator capability based solely on projected hardware improvements.

Voice understanding is very important for ease of input for Japanese and Chinese users of computers. This technology may consequently be viewed as, to some possibly major extent, pacing the rate at which those nations adopt IT.

The foregoing suggests that over the next 20 years, MT cannot be counted on to help many developing nations enter the information age. The reason is that MT and voice understanding technologies may be robust enough to enable high-quality translation between the most-frequently-used four or five languages in the world – and then in perhaps restricted domains. But the “shallow” translation that might be available for lesser-used (and perhaps then less profitable!) languages will provide only poor and unreliable translations of the informational riches of the Web (which will be available predominantly in English into the next decade or two, at least) into these other languages.

Bio-, nano-, and materials technologies

The synergistic contributions of biotechnology, materials technology, and nanotechnology hold significant promise to impact and expand the information revolution. From a conservative perspective, advances in nanotechnology will be needed to continue Moore's Law of exponential shrinking of semiconductor scale and resulting exponential increases in computational densities. Beyond semiconductors, however, on-chip integration of logic and other components will likely include chemical sensors and components, electro-optical devices, and biological components as well as microelectromechanical systems (MEMS). These systems will also leverage smart materials that combine sensing and actuating capability, integrating processing and function at the same scale. Sensors will be increasingly embedded within systems and devices to provide seamless and unobtrusive presence. Information interfaces will also become more integrated and could even provide direct neural stimulation and augmentation or replacement of sensory organs. Molecular manufacturing may begin to have impacts by 2020 although the pace of progress is uncertain.

The synergistic effects of these technologies can perhaps best be shown through example trends and paradigms. Health care is likely to be revolutionized by genetically informed prognosis, prevention, drug selection and treatment. On-person and laboratory microsystem diagnostics will likely improve diagnostics and early detection. Smart cards will likely improve health records management and access while providing both security challenges and solutions. The whole field of drug development may be revolutionized through: better tailoring of drugs through patient genotyping; higher drug approval rates in clinical trials through better understanding of genotypic bases of disease; reduced dependency on clinical trials through simulation; on-chip drug testing; and molecular modeling. Combined, these advances may lengthen life expectancies (especially in developed countries).

In another example, manufacturing may be revolutionized to enable customized product development at low cost as well as global part manufacturing.

Advances in rapid prototyping are already combining computer part modeling with 3D manufacturing processes to facilitate customization and part specification. Manufacturing robots with improved sensors, agility, reconfigurability, and intelligence will likely facilitate manufacturing agility and reconfiguration at lower cost. Agile manufacturing could revolutionize logistics and part reserves for some industries or classes of components. It could also enable new countries/regions to acquire technologies that will allow them to develop manufacturing niches if facilitated by local resources and transportation economics.

The information revolution, then, is taking place in a wider *technology revolution* where information technology is a key component but where other technologies such as biotechnology, nanotechnology, and materials technology synergistically enable new paradigms and effects.

Computing devices and artifacts

Silicon technology continues to improve at a pace that follows Moore's Law. The number of transistors per chip doubles every 18-24 months. This means that processor performance follows a similar exponential growth trajectory. The microprocessor of the year 2000 can operate at 1 Gigahertz, and provide something like 1000 MIPS. In the year 2011, we expect 10 Gigahertz and 100,000 MIPS. This rate of improvement is expected to continue for some time yet. The semiconductor industry now estimates it will be able to achieve minimum feature size of approximately 70 nanometers (nm) by 2009. Components per chip will improve by 50% due to gains from lithography, 25% for device and circuit innovation, and 25% for increased chip size (manufacturability). Chip performance is improved 10-20% using copper vs. aluminum-copper.

The supercomputer of the year 1988 was the Cray Y-MP8/4128, which had one Gbyte of RAM, peak Mflops of 1333, weighed more than 5000 lbs and cost approx. \$14M. Today, that same performance is expected of a Dell Notebook running a Pentium III, which will weigh under 5 lbs and cost under \$4000.

Existing handheld devices such as the Palm VII or the RIM BlackBerry provide wireless e-mail, two-way paging, and web access for under \$500. These services will be enhanced in the medium term to provide increasingly rich data access through such technologies as the Bluetooth protocol. At the same time mobile phones and pagers will add features to become increasingly "smart". Eventually

all these products will converge to create a (possibly modular) product whose overall characteristics and features cannot be fully anticipated. And the possible implications for user behavior are presently boundless!

These trends suggest that the following assumptions about the coming 20 years seem reasonable:

- There will be robust global information utilities with widely available service
- A variety of pervasive devices will be available, including wireless interfaces
- Information “appliances” will have intuitive interfaces accessible by many
- A large fraction (but very likely not a majority) of world population will become connected in one form or another
- Computing power will continue to rise according to Moore’s Law, or perhaps faster as concurrent architectures accelerate the gains from chip speeds alone
- Similar exponential increases will be seen in communications bandwidth
- Bio-sensors will be employed to identify users and detect and monitor other aspects of the environment
- Smart storage technologies will allow the personal high-capacity non-volatile storage of information

Given these assumptions, a variety of conclusions seem to follow:

- Sentient artifacts will make access to information technology and services much simpler and require much less sophisticated users
- Inexpensive artifacts imply very large user populations
- Artifacts will disappear into the environment, and the focus will move from devices to services with the central issues being utility, security, and the supply chain
- This reverses where the action happens, as large communications bandwidth and smart storage-enabled devices create a wide range of new engineering tradeoffs, such as between communications bandwidth and computation.

But, in spite of the rapid pace of technical progress, it may be difficult to overcome gaps in infrastructure to bring the have-nots into the game.

E-commerce and beyond

Information technology will create huge changes in commerce in the coming decades:

- Customers (including both businesses and end-users) will have very significant technical capabilities
- There will be billions of such customers
- There will be intense price competition
- New “value propositions” will be created – ways of creating value by providing wholly new services and facilities
- There will be increasing customer control and choice in market transactions
- Business must increasingly appeal to customer aesthetics.

Billions of customers and millions of businesses all interacting suggests the information economy will be a very complex system. Already, the Internet shows the statistics associated with classical “complex systems:” a power law dependency on site hit rates, links, and languages. This suggests that this economy will be characterized by the non-linear effects of such complex systems including lock-ins (of customers to specific sites) and the support of a diversity of small niches.

Such a system can be a rich domain for innovation, with a constant creation of new rules and structures. Napster may be a good example of how such a new paradigm can emerge, “from the bottom up.”

Increasingly, the physical world may be forced to align with the virtual world that coordinates it. The tension between real and virtual may vary sector by sector, but it is anticipated that the virtual may dominate, except in emergencies where physical constraints will still be central. (For example, logistics folks must increasingly perform to Star Trek-inspired standards.)

This will result in a swirling mix of old and new economy, with customers as adaptive agents whose behavior can be shaped, and businesses as virtual enterprises. A variety of evolutionary and revolutionary enterprises can be

anticipated. A mix of individual-business-government interactions will create a web ecology, with accompanying new social tensions. New social “things” will emerge.

Current e-commerce reflects a tool-building stage in a historic progression. In the longer term the prospects for fundamental change to business is real. Establishing trust is crucial to enabling business to business e-commerce. It enables transactions among partners to trusted relationships. Consequently, the set of concerns that often are given the label “privacy” could prove an important constraint that could impede the realization of these technology visions.

We speak easily of technology and usage of infrastructure, but what are the crucial (virtual?) artifacts that must be created to get to there? Computer Science research strives for “perfection”, but much of our daily experience is getting work done in spite of how bad the software is. Is it technology or engineering that drives/constrains the future?

Commoditization of interactions could serve to minimize the need for trust. Most of the interactions occurring in cyberspace, especially related to e-commerce, are in fact instances of a rather limited set of transactions: making requests or offers; making promises; fulfilling promises; making assertions. It is possible that use of greater precision and clarity in establishing such transactions could help enable systems establishing appropriate levels of trust within each type of transaction.

The availability of multiple personas for an individual person when interacting in cyberspace may allow us to deal with privacy issues in innovative and unprecedented ways.

3. Observations on Future Trends

**Observers: C. Richard Neu,
Peter Denning, Raj Reddy, Lily Wu**

Rapporteur: Richard Hundley

The next session of the conference involved a panel of observers whose purpose was to expose and elucidate assumptions in the previous presentations of technological visions that may have gone unstated or unnoticed by the speakers; to call attention to clashes among the various visions presented; and to discuss whether these clashes may result from differing assumptions.

Questions Posed by the Panel of Observers

The panel of observers approached their task by posing a series of questions to the conference audience.

The first observer began by emphasizing the importance, in considering the various technological visions that have been presented, of distinguishing between:

- Human needs/wants that will almost certainly be satisfied.
- Things that may not happen.³

The question he implicitly posed was: Of the many technological visions presented thus far, which fit into each of these two categories?

The second point the first observer raised concerned the many "information utilities" contained in various of the technological visions. He posed the question: How will we protect these information utilities from "trashing"? (The analogy used was the degree to which public restrooms and public phone booths

³ One example noted of "things that may not happen:" Widespread need for machine translation among human languages may be "trumped" by widespread use of English as a default language on the Internet and Web over the next two decades, if, as expected, these services spread primarily and initially to educated and elites of various countries that have adequate English comprehension.

in big cities tend to become defaced and “trashed” unless strongly protected by various access mechanisms.)

The second observer posed the question: Do we think it likely that Moore’s Law will continue for the next 15-20 years?

The third observer postulated a future in which there will be “infinite” memory and “infinite” bandwidth. As a consequence of this, he foresaw a future in which the broadcast industry will disappear and be replaced by “unicasting.” He posed the question: Is this plausible?

The last observer focused on *money* and *markets*. She put forward the following proposition: From all possible things that could happen, what is *likely* to happen will be determined by the availability of *money* and *markets*.⁴ This led her to pose two questions:

- What are the funding implications/sources for all of the technology futures that have been discussed in the various vision statements?
- What will people pay for? What will be the profitability of various technology developments?

Putting a non-U.S. hat on, she also posed a third question:

- How will the technology trends that have been discussed play in the non-Western world, where there are different legal structures, different feelings about privacy, etc.?

The Discussion

The remainder of the session was devoted to a discussion of these questions in which all of the conference attendees participated.

The Future of Broadcasting

One participant stated his firm belief that in a world of “infinite” bandwidth, broadcasting (i.e., the simultaneous transmission of the same material to many different individuals) will disappear and be replaced by “unicasting” (i.e., the transmission of material tailored specifically to each (and every) individual user). He cited “video on demand” as an early forerunner of unicasting.

⁴ She gave as an example of this proposition in action the change in the business model in the semiconductor industry in the 1980s, when the development of “foundry” fabrication facilities changed the economics of semiconductor design, development, and production.

Another participant reminded the audience of the impact of the printing press on society -- the last great information revolution in his view -- where contradictory effects happened simultaneously. The implied lesson he draws from this: We should be cautious in making dogmatic predictions about the future of "broadcasting," "unicasting," etc.

The Future of Moore's Law

One of the conference participants gave the following as the reason Moore's Law continues to work: The process (of semiconductor development) involves a number of separate, complex steps with a number of layers that can be independently improved. He cited biotechnology as another technology that could be subject to a Moore's-like law in the future.

Another participant noted that if Moore's Law were to continue unabated, in 2017 the individual feature size would be at the one-electron scale. The conclusion he draws from this: To continue Moore's Law unabated, we will have to leave silicon.

Still another participant noted that the big change (i.e., from individual transistors to integrated circuits) leading to Moore's Law came from the miniaturization of chips. In his view, sooner or later this will reach physical limits. When this happens, Moore's Law as we know it today will reach a limit, insofar as hardware is concerned.

Security of Information Utilities

One of the conference participants asserted that we have the technological capability to have adequate security for the information utilities and for other aspects of the information world. In response to this assertion, another participant noted that most of the computer security technology available today is not used on most of the computers in the world. He posed the question: Will this change over the next 20 years, and if so, why? His implication: if usage doesn't change, we may never have adequate security.

A third participant answered this question: Yes, this will change -- because we are now assigning economic value to transactions in cyberspace.

Elaborating on this, another participant noted that the scientific community, which initially developed the Internet, focused on authenticity and speed; e-commerce has a different security focus.

Elaborating further, still another participant mentioned that up to now IT developments have been driven by a community (i.e., academia) that was not interested in practical security. Sooner or later, in this person's view, IT development leadership will be taken over by the non-academic (i.e., commercial) community, which is interested in practical security matters.

Still another participant argued that this speaks to the security (awareness / performance) of individual organizations connected to the Internet. It doesn't speak to the collective security aspects of the net.⁵ To achieve an adequate level of collective security, she believes we need regulations for the security levels of entities connecting to the Internet.

Another participant explained that besides *security*, we need *trust* and *confidence*. According to this participant, E-bay and others are developing (or have developed) procedures to provide trust and confidence in Internet transactions.

Responding to this, the previous participant noted that *reliability* is also a problem. Today, reliability levels of computer systems fall into two distinct classes:

- Personal computers and small business computers, for which the achieved reliability levels are often low.
- Computer systems owned and operated by large organizations, for which the achieved reliability levels are usually high.

These differences occur because large organizations usually treat reliability and security in a more thoughtful, careful, complete manner than do small businesses and individuals.

Elaborating on this thought, another participant mentioned that the large multinational business organization of which he had once been a part treated risk management (of computer-related risks and other risks) in a very formal way. It drew profiles of the various things that could go wrong, assigned economic value to each of these risks, and assessed its capabilities to mitigate each risk. It did this once a quarter.

Still another participant said that the free market has mechanisms through which companies can offer effective security services, privacy, etc., *provided that governments and/or monopolies do not limit the technologies available*.

⁵ By the collective security aspects of the Internet she means situations in which a malevolent actor uses a security hole in party A's systems to cause damage not to party A but to party B, who could be on the opposite side of the world, totally unrelated to party A.

It was suggested that in the future, we should expect many more unconfigurable information devices or appliances, so that their security and reliability can't be compromised. (It is not clear, however, whether unconfigurability precludes various types of denial of service attacks.)

Another participant pointed out that there appears to be a market failure today. For security to sell, it has to be bundled and unobtrusive. Otherwise, people usually won't buy it. Another aspect of the market failure is that we can't today adequately measure risk, and therefore don't know how to value security.

Still another participant mentioned that market failures similar to this (i.e., safety or security problems) have occurred in the past in other industries. Effective solutions to such previous market-failure problems have usually involved:

- Public pressure by advocacy groups.
- Some form of government regulation, in response to this pressure.

He cited the impact that Ralph Nader (e.g., *Unsafe At Any Speed*) had on auto safety in the U.S. as an example of this phenomenon.

As a final word on the subject of security, one of the conference participants stated that: "Information security has got to get better. Therefore it will get better." (In other words, if it's required, it will happen.)

Other Drivers of Change

Changing the subject (somewhat), another conference participant noted that the entertainment industry -- which had not been mentioned up to now anywhere in the conference discussions -- will be an enormous driver of future technological change in the information world. This thought led the participant to pose a broader question: What are the different communities (in the information world) that will grow in importance over the next 20 years? He noted that these various communities may/will have different values, and these different values will shape the course of future change.

4. Technology Trends and Artifacts

Group Leader: William Caelli

Rapporteur: Jonathan Caulkins

The charter for this first breakout discussion group was to consider in more depth the various technology developments likely to occur in the next 15-20 years, then to consider specific artifacts likely to emerge in that time period as the result of those technology developments. Emphasis was to be placed on artifacts that have the greatest potential for affecting the lives, relationships, and business dealings of individuals, organizations, and countries or regions – with special attention to those that might have differential impacts across regions, cultures, or other boundaries.

The group, in a fairly open-ended brainstorming fashion, identified ten key technologies/artifacts that “will happen,” isolated a key assumption underlying those predictions, and listed two “tensions” whose resolution would affect what transpires in 15-20 years. Based on these observations, the group then sought to synthesize visions of the new worlds of physical systems, computer code, and human interactions.

Technologies/Artifacts that “will happen”

Over the next 15-20 years, literally thousands of new information technology-related artifacts will be developed, marketed, sold, and distributed widely. This breakout session could clearly not predict or list anything more than a very small selection. The following artifacts were chosen for discussion, as exemplars of likely futures that seemed particularly important – at least in developed countries – and not universally appreciated.

Developments

1. *Digital personas.* These are personalized databases or “agent” programs that accumulate a history of the location, movement, actions, and environment of

an individual. Much of this data is being collected now, e.g., in computer browser “cookie” files, in geographic tracking information generated by cellphones, and so on. The limits to the spread of this type of artifact are legal and social. The advantages of the personalization and tailoring of transactions made possible by such “digital personas” will encourage their spread, subject to some modest limitations. (But note an earlier comment in these proceedings that one person may develop – perhaps even cultivate – several such digital personas, providing some degree of privacy for some realms of activity.)

2. *High-resolution portable displays and wearable computers.* With continuing advances in wireless communication (see section 2 on Communications Technology), individuals will increasingly want continuing access to information resources while mobile. “Wearable computers” of various types – including “smart clothing” with embedded sensors connected to computing and communication resources – will proliferate.
3. *Major advances in input modalities.* This is an extension of the wearable computer concept to input/output devices (some portable) that enhance the user/computer interface by including all the senses: visual, audio, tactile, smell and taste. The group discussion even touched on monitoring of brain wave activity and rudimentary thought transfer, but there was much scepticism about how far these developments would extend by 2020.
4. *Ubiquitous, smart sensors and wireless connectivity.* This is perhaps the area with the greatest possible impact in about 20 years. If, as expected, some useful sensors become mass-produced to the extent that their per-unit cost is one dollar or less, they will become ubiquitous on devices, artifacts, clothing, and perhaps as embedded sensor/monitors. Their viability would be improved if the sensors could extract power for their operation from their environment. The largest impact may be in medical applications, but the conservative regulatory environment concerning medical innovation suggests that initially applications may focus more on: smart materials, construction uses, wide area networks for environmental sensing, and so on. To some extent, current international frequency spectrum allocation approaches will limit wireless capabilities, but as mentioned in Section 2 very localized wireless protocols such as Bluetooth can enable such sensors to communicate to a local “hub” (e.g., within 10 meters) that in turn is connected to larger networks. One uncertainty involves the long term medical consequences of these radiofrequency emissions on humans. We need better understanding of the biological effects before use of wireless systems – especially those in close contact with humans – becomes

ubiquitous not only because of the "objective" risks but also because of the possibility that "irrational" or media-hyped fears of such risks would block widespread deployment even if the risks are not in fact large.

5. *Soft control of hardware.* The U.S. military is investing heavily in software-controlled radios. This is one small example of hardware that is substantially reconfigurable through software, allowing devices to evolve more gracefully to keep up with the rapidly changing demands of the information revolution. Such greater software control of hardware will increase.
6. *Ubiquitous digital access to the net.* As mentioned elsewhere in this report, widespread accessibility of "the net" from a rich variety of devices and locations is a common prediction. One highly-prized application would be the ability to anonymously browse the net. This is technically feasible, but subject to possible legal and social constraints yet to be worked out. The outcomes may well differ among countries, regions, and cultures.
7. *Collapse of the switched network.* If traditional switched telecommunications service (such as traditional voice telephone service to homes) is replaced in most locales by packet-switched technology, there are implications for the urban vs. rural digital divide. When most people bypass switched services, how can costs be recovered to support the remaining pockets of subscribers not yet reached by broadband packet services?
8. *Trusted mobile code.* Mobile code is software that migrates over networks to various client machines, for local execution. An example is an e-mail attachment that executes in some manner when accessed – for example a Word document with embedded macros that launch when the document is opened. Such mobile code is currently a major source of virus and worm attacks. The discussion group expects protocols and safeguards to be worked out so that mobile code received and executed under normal conditions can be trusted. The problem is more administrative and procedural than technical.
9. *Major advances in computer mediated human interactions, particularly asynchronous ones.* Electronic mail (e-mail) is a common form of asynchronous computer-mediated communication. It is the most widely used application on the Internet. The group felt that major advancements in such asynchronous communication were likely. (Video conferencing will become commonplace also, but it is deemed a less important revolution than advances in asynchronous interaction, due to the major advantages of asynchronicity in human communication.)

10. *Great imaging interfaces.* Visual displays provide tremendous bandwidth between computing and communication devices and their human users. Because of the importance of these displays to the whole user-computer interface experience, they will continue to improve in resolution, size, thinness, and other useful attributes. These developments will be spurred by the entertainment industry and its high-definition TV, gaming systems, and the like.

Assumption

A major assumption underlying the above developments that was highlighted by the discussion group is that: The US government will succeed in establishing necessary commonalities to avoid balkanization from desires for proprietary control leading to multiple protocols overlaid on top of each other, which would be a major problem. The word "commonalities" was selected over "standards" intentionally. The feeling was that ANSI, ISO, etc. would not be the key, but rather that implicit or explicit government sanction of particular approaches would, via first mover advantage, focus the market's efforts on one architecture, language, protocol, etc. over another. It was observed that it is getting harder to tip the market by being an early trendsetter because the big firms in the private sector move so fast, and government has withdrawn from the roles of ensuring safety and security that it plays in other sectors. A subset of the group argued that the US government has historically played this role (e.g., through DARPA) and would continue to successfully walk the line between meddlesome interference (as sometimes exhibited, for example, by Singapore) and a completely laissez-faire approach (e.g., the approach often taken by Australia). Another faction pointed to the inability to write Postscript files from new versions of Word as a worrying portent of a less optimistic future. The group concluded that:

"In its role of helping to improve the innovation process, the government will help guide the development of interfaces that enable multiple interactions of artifacts. Rapid change in the marketplace leads to unpredictability, which deters development of useful interface guidelines."

The question and answer session when these results were briefed to the larger conference indicated that others were skeptical of this rosy view, preferring perhaps a statement that the government "needs to help guide the development" of these interfaces, not that it necessarily will do so wisely. It is a key assumption, not an innocuous one.

Tensions

Two tensions resulting from the above developments were highlighted by the discussion group: ones involving open vs. closed “worlds,” the other involving the strength of intellectual property right protections.

1) *Open vs. Closed worlds.* Powerful trends/incentives were seen pulling toward both the closed and the open end of the spectrum, dubbed the “Windows” and “Linux” scenarios. The image of the closed world was “shrink wrapped” products that would not allow users to “look under the hood” or tinker (tamper) with underlying “code.” The prototypical example is Microsoft’s unwillingness to sell its assembler. The open image was a “new regime of simplicity” in which the drivers are trust, mobility of code, and linking of applications. A statement by one participant was that “The days of the non-sandboxed interactions are numbered and PEPC (privacy enhanced personal computers) will be the norm.”

There was no consensus on which trend would “win.” Indeed, there was a reluctance to see this as an either/or proposition. The “market share” of the two approaches might cycle, or perhaps it would always be possible to “own the code” but only by paying a “hit on capability.”

2) *Strength of IP (intellectual property right) protections.* The group believed that IP rules in a web-world are still up for grabs in important ways, and the future depends very much on how the law comes down. Two examples of the uncertainty were: (1) Caching and fair use. Libraries do not violate copyright when they loan a book because that is “fair use”. When persons download information from the web, they are making copies (on their machines, on mirror sites). Will that remain within fair use? (2) Is it legal to make a pointer to Napster? There was a notion that at present it is OK to make a pointer to its head but not using “deep linking” -- but one could imagine more such “test cases” in the future.

The group saw a trend toward more power for IP holders. “We’re creating legal and technical mechanisms that enhance the ability of IP entities to retain control. That runs counter to the openness of the internet.”

Developments most likely to occur, and most consequential

When asked to select and detail the technologies/artifacts that are “most likely to occur” and whose occurrence would be “most consequential” the group selected three visions of a “new world.” The consensus of observers is that the group,

perhaps unconsciously, defined these criteria as “most likely to be technically possible within the forecast horizon (e.g., 15-20 years) and to be most consequential in the long run,” not as “most likely to have become most consequential within that 15-20 year time horizon.”

They chose to present their deliberations in terms of three “new worlds:” the New World of Physical Systems, the New World of Code, and the New World of Human Interaction.

The New World of Physical Systems

The group believed (as outlined in Section 2) that we are on the verge of a revolutionary explosion in sensor and wireless communication capabilities and reduction in cost to achieve those capabilities. This “New World of Physical Systems” vision emerged by building on that premise. It is defined as “The existence and deployment of active/passive sensors, communicators, and related devices with associated (wireless) communications capabilities that make participation in an information environment fully possible – with embedded knowledge and information models to know how to use all this information.” Smart highways and smart houses/offices are signal examples. (Note: the notion of smart structures wasn’t confined to such visions as refrigerators that automatically order groceries. It includes smart materials and structures that adapt to physical stresses, e.g., materials that sense they are near the onset of failure and smartly repair themselves such as might occur in earthquakes or, chameleon-like battle tanks that blend in with their environment.)

The breakthrough technology was the capacity to saturate physical space with sensors that have embedded “knowledge” of the information environment in which they are deployed. (There was no consensus on whether this intelligence would be centralized or distributed.) One of the key limiting factors of this new world of physical systems is the inability of the international community to come to grips with the issue of spectrum usage among countries, so wireless systems can operate anywhere in the world without interference effects. It is a politically driven issue, since the international governing body charged with this problem cannot agree on procedures for sharing the spectrum across national boundaries.

The overall group feeling about this New World of Physical Systems was: “This changes everything.” However, the group spent little time elaborating on this statement precisely because the effects were so numerous.

The main effect of this vision is a strong coupling of physical and cyber space.

A key tension was that too much information can lead to privacy concerns (think "The Truman Show") and legal liabilities. (If the sensor owned by an entity knew of some threat, flaw, or presence, then it might create legal liability for the owner if that threat, flaw, or presence led to harm.) The optimistic view was that any individual could at any time say "sensors off" to protect privacy, but that could render ubiquitous sensors moot in public spaces where there might almost always be at least one privacy advocate. The ability of the legal, social, and political systems to cope with this new world was doubted, but there seemed to be an implicit assumption that the technology would win.⁶

The group briefly discussed possible differential regional effects of this New World of Physical Systems. They felt that participation in this sensor-laden environment could become compulsory in regimes without privacy protections (China?) with 1984-like implications. Group members said, "Imagine the threat from micro-cameras and then multiply ten-fold."

There was discussion of how long it would take for a "Moore's Law of Sensors" to make sensors so common (to the point of disposability) that this vision would be realized. The notion was that when cost is reduced to \$1 - \$2 we'd have reached that stage. That is, the key metric does not pertain to the accuracy or precision of the sensor, but rather to yield of usable units per wafer. That will be achieved sooner for some types of sensors (accelerometers) than others (medical sensors). Specifically, the expectations for such inexpensive, mass-produced and ubiquitous sensors were:

- Accelerometers (now)
- Food spoilage detectors in plastic food wrap (now)
- Gyroscopes (1 year)
- Cameras (3 years)
- MEMS microphones (3-4 years)
- Smell (e.g., for bomb detection) (5 years) – Smell actuation will be longer than detection
- Bio-sensors (e.g., for Legionnaire's disease) 5 – 20 years
- Medical (10 – 20 years)

In addition, polymer-based sensors were also noted by an expert as being a very important development.

⁶ Aside: The rapporteur's personal view is the opposite, that legal and privacy constraints (as well as the constraints of legacy physical infrastructure) will mean only private spaces inhabited by first-world people from the upper half of the income distribution will be saturated with these networked sensors within the next 20 years. Non-networked (less intelligent) sensors (along the lines of lights triggered by motion sensors and automatic traffic signals) will be the more common form in public spaces.

It was felt that the bio / medical sensors will take longer to develop because of FDA regulations and concerns. Also, part of the vision involved sensors being fairly autonomous with respect to their power source. There were conflicting statements about whether that might be a constraint. The group was not very clear as to whether the times estimates shown above are unconditional, or whether they are conditional on advances in power sources for applications in which the sensor would not be connected to some external source of power (whether electrical or mechanical, such as deriving power from being part of a moving object). One of the tradeoffs is how much information processing and storage is put into the sensor device itself; more intelligence in the sensor will inevitably lead to lower communications requirements, which can in turn reduce power requirements. The group didn't have time to explore this issue in depth, but it is an important tradeoff that must be considered.

It was noted that the automobile industry could be key in pushing low-cost sensor technology forward because they use sensors in large enough numbers to push costs down the economies of scale curve. (This is already the case with sensors in air bags and accelerometers in automated braking systems (ABS); the next generation of cars could have gyros in ABS as well.)

The New World of Code

There is a trend toward more explicit management and representation of trust and verification, analysis, and encapsulation of mobile received code. These characteristics are currently used to assure that the code does not do something it shouldn't, but will eventually also apply to making sure it does what it's supposed to do. Developments in this area will allow construction of large-scale, distributed, component-based, multi-sourced, trustworthy code. This accomplishment rests on five related developments:

- Development of trust-supporting networks, which include the local (client) operating system. This is a matter of changing conventions and implementing technologies we have now. It involves configuring existing systems for privacy and security, and the emergence of safety-enhanced Internet Service Providers (ISPs).
- Client-side means of proof and verification, including better understanding of methods and procedures for evaluating received code – such as better "sandboxes" that provide absolute safety for small pieces of code.
- Means of becoming certified as a trustworthy provider of code (e.g., by certifying the provider through a third party like Underwriters Laboratories).

- Compilers and structures that allow software producers to produce trusted mobile code. That is, an enabling technology that lets people produce and verify the software components themselves.
- Articulation of security and privacy policies and reasoning about those policies, advanced sufficiently to support the other aspects of this prediction. (There was a notion that “Implementing security and privacy is easy; defining, articulating, and reasoning about security policy is hard.”) There was also discussion that two possible ways of achieving safe use of received code are: (1) prevention techniques, and (2) mitigation techniques. The latter recognize that damage done by failures is usually bounded, and so it should be possible to develop procedures to repair these failures. This leads to the strategy: prevent, detect, tolerate.

If this New World of Code becomes viable, it was felt that tradable/trusted code will be a major enabler, along with robustness, for all industries and sectors that use information technology.

What might be regional/cultural effects of these developments? To the extent that we develop client-side means of proof and verification (e.g., through “sandboxes” or similar methods), it might help small countries or new suppliers to sell IT products, because without these breakthroughs there may be a tendency only to buy from name brand producers.

An assumption underlying these developments is the need for the next generation of compiler and software generation tools, and reversal of the trend of lack of attention to configuration management.

The New World of Human Interaction

New systems will be developed to revolutionize human-to-human contact and interaction, particularly in asynchronous communications with appropriate parameters of discourse. Enabling collaboration often focuses on video-conferencing (a synchronous technology), and the group believed that better video 20 years from now is a given. But there was a notion that the bigger payoff will actually come from improved technologies for asynchronous interaction, since most work interactions are in asynchronous mode. The motivating example is an observation made by one of the group members that email hasn’t changed a bit since he started using it in 1973. The average e-mail user has 200-300 threads going at once, and the best technical support is “raw” searching. There are great inefficiencies in a user’s constantly context switching among various threads of discourse in which he or she is involved.

Other examples offered were the need for better calendaring, intelligent chat rooms, and "family reunion sites".⁷ The idea is that the latter could find commercial applications in domains such as reducing medical errors. More widespread application of methods such as used by moviecritic.com was also mentioned.⁸

Discussants thought widespread use of these developments could have an "incredible" effect on the work environment.

There could well be differential regional effects in use of these developments, because there are regional differences in work habits and mores. Although the group mentioned various possible regional effects, there wasn't the time or empirical basis for evaluating the different stories. A possible effect might result from efforts to bridge between cultures by enabling communication among workers who span cultures. These cultural differences might make it harder to develop the tools for small-market cultures (a possible advantage for the US) or they might help break down barriers between cultures. Analogies were made to machine translation of culture as well as language (to the advantage of small-market cultures). On the other hand, these tools might promote a single, global work culture in the way that English is emerging as the *lingua franca* of commerce and science. If that were to occur, US mores might be disproportionately represented.

The main assumption underlying the above "world" is that our understanding of human interaction and work processes will advance sufficiently. That is, the technical hurdle is probably not in the software engineering but in the sociology. However, the market demand is huge: So many people use email that a major improvement in one's efficiency at processing email would have a lot of buyers. So nontrivial investment in this development could be justified.

⁷ These were discussed as sites where members of a group (e.g., an extended family) can post and share information among themselves, the way people do for funerals, weddings, and the like.

⁸ The "technology" involved is using your stated preferences with respect to some domain elements (e.g., movies) to match you with other respondents for purposes of using their opinions of a domain element you haven't sampled to predict how you'll react to that domain sample. I.e., instead of assuming Roger Ebert knows your tastes, you search over a large population of respondents to find kindred spirits.

5. Services

Group Leader: Colin Crook

Rapporteur: C. Richard Neu

Information Technology and the Character of Business

The group began its discussions by noting that the character of business activity is changing in important ways. These changes are facilitated and, arguably, in some cases caused by, developments in information technology (IT). To date, these changes are most visible in the United States, but they are occurring throughout the industrialized world.

Perhaps the most striking of these changes is the shift in business emphasis away from products to services. Increasingly, businesses see specific products as elements or components of a broader service that the firm provides to customers. Firms work with customers to identify a need, design strategies to meet the need, deliver necessary products, instruct customers in the proper use of products, provide maintenance and oversight of the products, help customers to recognize the need for follow-on products, and so on. In some cases, the product is in fact never delivered to the customer; the firm simply operates the product on behalf of the customer. One member described the recent history of a major producer of scientific test equipment: Once, this firm simply manufactured test equipment that it sold to customers. Customers began to ask for advice on the most appropriate equipment. After a while, customers stopped purchasing equipment, preferring to lease it instead and relying on the provider to notify them when new and improved models became available. Eventually, customers stopped even leasing equipment. Now, they prefer simply to buy test services from the manufacturer. This pattern, several members of the group noted, is being repeated in many industries.

IT is central to this new business model for a number of reasons. This new model for doing business requires much more interaction between producers and customers than did traditional business models. IT facilitates this interaction. IT also allows services to be highly tailored to the needs of specific

customers. Finally, as services rather than products come to dominate economic activities, delivery mechanisms change, and IT becomes the dominant distribution modality. A firm that once relied on a fleet of trucks to deliver test equipment now uses high-speed data links to deliver test results.

Economies of scale and the advantages that accrue to first-movers are likely to become more pronounced in the emerging economy of IT-intermediated services. Standardized procedures and protocols for moving and using information facilitate interactions with customers, suppliers, and partners. Firms that set standards later adopted by others and firms that are able to exploit large volumes of information about potential customers and partners will thrive and become even more dominant. Consequently, firms that once hid technical details are now making these details publicly available in order to encourage others to adopt their standards. Although dominance by a single firm may be characteristic of the new service economy, this dominance may be less enduring than in the old product-oriented economy. IT technology and its applications are changing rapidly. A single firm may be dominant for the entire life of an industry, but whole industries may be ephemeral. Some members of the group opined, for example, that the U.S. Department of Justice is too late in seeking to break up Microsoft. The industry that Microsoft dominates is likely to be gone or drastically altered in the next few years.

IT is also changing the structure of firms. In an era when information was scarce and moving information was difficult and costly, large, hierarchically organized, multi-functional firms allowed efficient information utilization and management. Information was collected in and passed upward through a single centralized reporting chain. At each level, managers scrutinized and combined the sparse information available and sent necessary instructions back down to subordinates, who typically knew and needed to know little of what was happening in other parts of the organization. Mid-level managers would suppress some information and pass what remained on to higher levels. Effective information management structures were rare. Whenever such a structure was created, there were strong incentives to use it for multiple purposes. The result were large corporations that attempted (and often succeeded) in managing very different lines of business.

As information becomes plentiful and moving it becomes easy, the rationale for these organizational structures is eroded. Now, the flow of information is too large for managers to digest. The task of coordinating activities among different units of a large organization is delegated to the units themselves, and units are expected to communicate with each other to understand what each needs and what each can offer. In some cases, it becomes apparent that there is no longer any reason for units performing very different functions to be part of the same

organization. If they are successfully exchanging information and coordinating their activities without the intervention of some common manager, they have become effectively independent. When the availability and management of information is no longer a binding constraint, the incentive to use a single information management chain to accomplish many different functions is reduced. Thus, the rationale for placing a single effective information management system at the center of a large, multifaceted enterprise goes away. Increasingly, the key to business success seems to creating valuable partnerships rather than integrating diverse activities into a single company. By facilitating the flow of information, IT clears the way for a richer variety of management structures.

What we see in the emerging service-oriented and IT-intermediated economy, then, are simultaneous incentives for both consolidation and divestiture. To capture economies of scale, firms in roughly the same lines of business will benefit if they can combine and increase the scale of their operations. But because it is now easier to partner with or otherwise to obtain non-core functions from other enterprises, firms are spinning off functions peripheral to their core competencies.

Some members of the group saw parallels between the IT industry today and the early years of the auto industry. In their early stages, both industries were marked by many firms trying to produce final products from start to finish. In time, though, a small number of large integrators or final assemblers emerge, which buy component parts and support services from a huge number of much smaller specialty firms. In the auto industry, the specialty firms provide windshields, design services, safety engineering, and marketing, among many other things. In the IT sector, specialty firms will provide customer service, billing, payments processing, information about customers, subsidiary software, Internet access, Web hosting and so on.

The new business plans facilitated by IT developments will pose some difficult choices for those who adopt them. Close interactions between customers and suppliers will allow the production of highly tailored products and services. Sharing of information about requirements, capabilities, and processes will make it easier to establish successful business relationships. But none of this can be accomplished without a loss of privacy: characteristics of buyers, sellers, and business partners that were once closely held will have to be shared. It may turn out that choice, efficiency, and convenience will be available only to those who are willing to forego privacy and vice versa. How the information revolution affects business practices and societies more generally will depend importantly on how different individuals and different cultures balance choice, convenience,

and efficiency against privacy. Some members of the group saw this conflict of values as giving rise to an entire new industry of trusted intermediaries that would allow parties to share information anonymously.

A Structure for Thinking about Information Technology and Services

Early in its discussions, the group recognized that effective use of IT in delivering final services will require a host of intermediate and enabling IT services. A few key enabling services will be essential for effective delivery of many final services. Robust security for records and communications, for example, will be essential for medical, financial, governmental, and many other kinds of services. To capture this interaction between final and enabling services, the group decided to structure its discussions in the form of a matrix in which the columns represent examples of potentially important final services and the rows some of the more important key enabling services.

Time limitations forced the group to concentrate on a small number of each type of service. The final services that the group discussed were health care, education, entertainment, and supply-chain management. The enabling services discussed were security, payment, validation, and “dynamic brokering.” The group sought to understand how each of the final services would make use of the enabling services. Thus, matrix in Fig. 5.1 represents the space for group discussions.

	Health Care	Education	Entertainment	Supply-Chain Management
Security				
Validation				
Payment				
“Dynamic Brokerage”				

Figure 5.1 – A Framework for Information Technology and Services

The remainder of this section summarizes group discussions first regarding the enabling and then the final services.

Enabling Services

Security

There was strong consensus within the group that security would be a paramount concern for almost all IT-intermediated services. As more and more parties share increasing volumes of information, the responsibility of each party to protect information grows. (One member of the group noted that his firm has and protects proprietary information from more than 7,000 partners.) IT enormously expands choices of suppliers and partners. Any firm that fails to provide adequate security will find its customers and partners going elsewhere.

As services become more seamless, so must security. Security cannot, the group agreed, be added as an afterthought. True security for IT-intermediated business must be end-to-end and built into business process from the beginning. As security becomes more complex and demanding, many firms will prefer to buy security solutions from specialist firms rather than to develop and to maintain their own security procedures.

As the demands for security grow, so will challenges to security. Because the emerging service economy will have a strongly winner-take-all character, disruption of the operations of the current front runner may appear to be an increasingly attractive strategy for displacing or punishing a dominant player. Further, since the benefits of the new service economy are likely to be unevenly distributed, some nations or groups may perceive that they have little to lose if the information economy is disrupted. Finally, as firms become repositories of increasing amounts of private or proprietary data, vulnerability to corrupt or disgruntled employees will rise.

There was general agreement within the group that working at the frontiers of IT and IT applications requires simultaneously working at the frontiers of IT security. Some in the group severely criticized current U.S. government policies restricting export of encryption technology as hindering overall progress toward a truly secure IT environment. If strong encryption and authentication procedures had been widely in place, one member archly observed, the "Love Bug" virus that caused so much trouble in the weeks just before this conference would never have spread. Certainly, strong encryption will pose challenges for intelligence services and law enforcement. But we simply have to learn to deal

with strong encryption. To live without secure IT will be much worse. Without very good cybersecurity, some members predicted, the next few years will almost certainly see some sort of serious "train-wreck"--a large-scale compromise of sensitive personal or business information--that could sour an entire generation on IT-intermediated services.

Payment

One of the key advantages of new information technologies is that they can make information and services widely available at very low costs. Unfortunately, there is today no fully satisfactory way to manage the large volume of small payments (so-called micropayments) that will potentially be generated by on-line services. Subscription services are impractical for occasional users. The costs of processing a credit card payment are prohibitive for small transactions. The group noted its expectation that firms offering cost-effective micropayment services are likely to appear in the next few years.

Validation

IT developments are bringing an enormous expansion in the number of channels through which information can flow. In general, the group viewed this as salutary. Advantages that accrued to narrow groups by virtue of their control over information are being eroded, and the benefits of access to information are becoming more widespread.

The group recognized, though, a danger in the proliferation of information channels: Some (much?) of the information that moves through these new channels may be wrong, misleading, dangerous, or otherwise "invalid." As control over information diminishes, traditional mechanisms for screening, checking, or editing information are weakened. Users of information will encounter increasing difficulty knowing what purported information is to be trusted.

For some applications--health care and education come immediately to mind--the quality, authenticity, and integrity of alleged information will be of enormous importance. The group noted that new approaches to certifying the quality of information will have to be found. In some cases, information might be effectively "branded;" if you find information on a trusted web-site, you will have confidence that it is reliable. But more elaborate mechanisms may be required: watchdog groups; voluntary associations of information providers in

certain fields; certifying bodies; etc. Few such mechanisms have evolved so far, but the group saw them as necessary and inevitable.

"Dynamic Brokerage" Services

Several members of the group offered the view that the huge variety of IT-intermediated services that will soon be available and the need to customize these services and combine them with other services will give rise to an entirely new kind of enabling service, which they termed "dynamic brokering." Group members envisioned a decentralized capability for matching highly specific requests from customers for packages of services with suitable offers of these services from a wide range of suppliers. No single supplier would necessarily be able to provide all of the services requested by a customer. The power of the dynamic brokering capability would lie in the ease with which a customer could identify and then combine services from many providers to create the specific package he or she requires. Sufficient standardization of interfaces would eliminate the need for the providers of the various component services that make up an entire package to collaborate directly or even to be aware of each other's identities. This brokerage capability would be dynamic in the sense that customers would use it to find necessary services when and as they need them and to find different suppliers to meet different requirements from one day to the next. The system would be decentralized in that there would not have to be any central repository of information. Requests would be routed to possible suppliers in a way analogous to the way that e-mail messages move today.

The key to creating this sort of a brokering system lies in the creation of a standard vocabulary for articulating requests for services. Members of the group noted that several attempts to create such vocabularies are already underway, and that the coding necessary to implement a good brokering system is probably not particularly challenging. One member estimated that a good dynamic broker would require on the order of 100,000 lines of code. Predictions were that this kind of a capability will be feasible in about five years and that the changing character of the services market will make demand for such a service very strong.

Some members argued that the arrival of this kind of service will dramatically change the character of IT industries. By working through this new "distribution layer," users will be able to access the IT services without actually having to perform IT functions locally. The market for "shrink-wrapped" software distributed on disks will largely disappear. Indeed, the market for "owned" software--however distributed--will probably shrink. Because users will buy IT services rather than IT itself, we will see a proliferation of specialized terminals

and access devices that incorporate simple, generic approaches to accessing available services. Demand for powerful multi-purpose computers and for the complex operating systems that control such devices will decrease markedly. (Some members noted that the large installed base of such hardware and software may stand in the way of the new distributed information and services structure--but only temporarily.) One member predicted that the arrival of this kind of brokering capability would lead to broad reinvention of the whole field of computer science, in the course of which we would re-discover the virtues of simple, elegant, older systems.

In a particularly apt metaphor, this new distributed information structure was characterized as an "information plug" similar to the ubiquitous electric outlet. You can plug any kind of an appliance into an electric outlet, because you understand what will come out of it. A standard vocabulary for requesting and receiving information will allow equally flexible use of this new information outlet. Perhaps most important, this new distribution apparatus will NOT divide the world into haves and have-nots. Because this new information structure will enable many new kinds of devices and access modes, all people will stand to benefit.

Final Services

Health Care

The group noted strong pressure within the health services sector to provide more and better care without spending additional resources. This pressure, they felt, would provide a strong motivation to find ways to provide health care and related services remotely. Developments in information and communications technology, they argued, would make remote care a reality within a few years. In industrialized countries, the necessary communications infrastructure will be available. So will a wide array of sensors that will allow remote monitoring of vital signs and health status. Electronic medical records, easily transferable and containing detailed images, will soon be commonplace. The group expected that within the next fifteen years, a significant fraction of all diagnoses will be made remotely. The physician and the patient need not be in the same location.

The arrival of true telemedicine (as IT-mediated health care has come to be called) will likely bring profound changes in the organization of health care. Both patients and health-care professionals will have access to experts, wherever these experts happen to be located. This will probably reinforce the economies of

scale that are already emerging in medical care, which give a decided advantage to specialists who treat large numbers of particular kinds of patients and develop special expertise. Nonetheless, telemedicine will probably also give rise to a variety of subcontractors who will provide necessary in-person care and who will help direct patients to specialists. Information about health and health care will be more accessible, and patients will be much better informed than in the past. Access to second opinions and alternative views on proper treatments will become routine. Patients will also have access to information about the effectiveness of various treatments and the success rates of various practitioners. Because access to multiple health-care providers will be made easier, local monopolies will be eroded, and the health-care sector will see increasing competition.

Telemedicine will, of course, require a very high level of information and communications security. Indeed, the health-care sector is already one of the main drivers of advances in information and communications security.

Telemedicine will also require a very high level of validation services. There will be very strong demand for mechanisms that will ensure that information and diagnoses provided on-line are in fact correct. This demand will be so strong, the group believed, that mechanisms will undoubtedly be developed to meet it. Little progress has been made in this direction to date, though, and precisely what these mechanisms will be, is hard to predict. Almost certainly, geographically based licensing of health-care providers (e.g. state medical licenses) will be inadequate, since the whole point of telemedicine will be to erase geographical boundaries. Local regulators, the group predicted, will try to slow the advance of telemedicine, but these regulators are bound to fail. The attractions of remote health care will simply be too great. A more likely solution will be some form of "branding." Remote providers will organize themselves under the supervision of a few prominent institutions, which will vouch for the quality of care provided under their "marque." Prestigious clinic and medical centers already provide assurances regarding the quality of care provided by their associated physicians. Extending such assurances to cover care providers reached through communications channels established by the clinic or medical center does not appear to be a dramatic departure from current practice.

The opportunity to access information and actual care from a vastly expanded set of providers will confront both patients and health-care professionals with a bewildering array of choices. In these circumstances, an efficient means of finding the appropriate provider will be essential. For this reason, telemedicine is likely to provide a strong impetus to the development of dynamic brokering services.

Professional health-care services delivered electronically will probably not generate heavy demands for payment services. Unfortunately perhaps, health-care services are typically sufficiently expensive that traditional payments methods (such as credit cards) will probably suffice. Occasional access to medical information, however, may require micropayments. Given the apparent appetite of consumers in industrialized countries for health-related information, health information could become one of the earlier applications of micropayment technologies.

The development of telemedicine will probably widen the gap between rich societies and poor societies. Effective telemedicine will require enormous bandwidth, and only countries that can create the necessary infrastructure will be able to exploit the full benefits of telemedicine. Even so, some benefits may accrue to poorer countries. Medical students and practitioners in these countries may gain improved access to information and training, for example. One member of the group also noted efforts now underway within the U.S. military to develop a "smart stretcher" that will transmit detailed information about a wounded soldier to physicians at a central location who can then instruct a medical corpsman to take particular actions. Technology of this sort might eventually prove highly valuable in countries that are short of trained medical personnel.

The group believed that advances such as those outlined here are close to inevitable. They may be delayed, however, by regulatory rigidities and by the generally conservative attitudes of health-care professionals. One member suggested, however, that these attitudes might be changing. With telemedicine a realistic possibility, he noted, entrepreneurs and innovators may once again find the medical field appealing.

Education

The group expected that new information and communications technologies will bring important changes in education and training in the next fifteen years. In particular, these technologies will give a strong impetus to "distance learning," allowing students remote access to teachers and educational materials.

The group noted that educational applications of IT will probably require less security than health-care applications and less sophisticated payment arrangements than entertainment. Consequently, educational applications should be able to "piggy-back" on enabling services in these two areas that are developed for other purposes. In contrast, validation--guaranteeing the quality, correctness, and effectiveness of education services--will in some applications be

very challenging. Similarly, the brokering function that matches students with educational resources will have to be quite sophisticated.

The group also noted that, like medical applications of IT, political structures, regulators, and the conservative attitudes of many educators will resist educational applications.

The group recognized that IT will be differentially effective at different levels of education and will be adopted more easily at some levels than at others.⁹

- Perhaps the earliest and most dramatic educational applications of IT will be in the areas of **lifetime learning and specialized training**. These areas are burdened with few regulatory constraints, and there is already keen competition among providers of such educational services. An ability to provide instruction tailored to individual students' needs, remotely, and at a time that is convenient for the students will be a strong competitive advantage. Consequently, the group expected considerable effort and resources to be devoted to developing innovative distance learning techniques and the facilities necessary to exploit them. Validation is relatively simple in these settings. Students will generally be well placed to assess whether the training they are receiving meets their needs.
- IT will also bring important changes to **post-graduate education**, where it will allow students to "customize" their degree programs, enjoying lectures from and consultations with professors at multiple universities. The reputation of professors will be the principal guarantee of quality, and so complex validating systems will probably not be required.
- Opportunities will be more constrained at the **university undergraduate level**, where social aspects of education are more important and where faculty committees and conservative establishments may hold greater sway. Nonetheless, there is already strong competition among universities for the best students, and universities will be under considerable pressure to develop innovative teaching techniques and highly tailored instructional programs that will make extensive use of emerging IT capabilities.
- It is at the **K-12** level, where IT applications will prove most problematic. Inertia, entrenched unions, unfamiliarity with and inability to use new technologies, the costs of acquiring equipment and building infrastructure, and (for public schools) political interference will all constitute serious

⁹ These views are based on a U.S. perspective. The situation may well differ in other nations.

barriers to adoption of new IT-based teaching techniques. Validation of techniques and information provided on-line will also be problematic. In many cases, parents and administrators will be unable to judge the quality of IT-intermediated services, and they will consequently be reluctant to adopt new approaches. Some members of the group predicted increased use of IT to facilitate standardized testing, a prospect that most in the group found unattractive.

Full exploitation of IT-intermediated educational services will require considerable investment in equipment, facilities, and infrastructure. It will also require the services of highly skilled, dedicated, and much-in-demand educators who can develop effective new teaching methods to be used in conjunction with new media. Consequently, the group predicted advances in educational use of IT are likely to prove divisive along lines of income and wealth: Individuals, communities, and societies with the resources to take advantage of new opportunities will flourish and further increase their advantages over those who are not so fortunate. The group also noted that expanded use of IT for education will tend to make education less specific to particular societies or cultures. It will become harder to use education to shape a particular national or group identity.

Finally, the group noted that many techniques for educational uses of IT will likely be derived from the entertainment industry. Because the entertainment industry is largely unregulated, faces few resource constraints, and enjoys an innovative culture, we might expect many more new ideas and techniques to spring up in the entertainment context than in the educational context. For better or for worse, many of these techniques will be transferred to educational applications.

Entertainment

There was general agreement within the group that entertainment applications would be the most powerful drivers of IT developments in the next fifteen years. Entertainment will create the demand for high-band-width infrastructures, for new terminals and access devices, and for new software. New information "pipes" will be filled primarily with entertainment, and, as one group member put it, "all the other good stuff will come through the cracks in entertainment."

Members of the group predicted a variety of entertainment-related applications that may have the capacity to change the way people interact and perceive the world around them:

- Multi-person, computer-based games are just beginning to emerge. These games will create new spaces and new modalities for human interaction, with consequences that are difficult to forecast.
- Within the next fifteen years, group members predicted, web-mediated physical activity would be commonplace. With the aid of new sensors and physical feedback devices, interactive games that now involve only the movement of a joystick may evolve into games that require strenuous physical responses. In the future, the notion that IT produces "couch potatoes" may seem quaint.
- Web-cams will become much more common, allowing good things (e.g., improved interpersonal interaction at a distance) and bad things (intrusive surveillance).
- Interactions with people from very different cultures will become easy and commonplace, particularly if effective translation programs are developed.
- A multitude of hobby and special interest groups will proliferate, not all of which will prove socially constructive.
- With enough computing power (surely coming) and enough digital imaging devices to record events from many angles (also coming), it will become possible for viewers to experience events (athletic or cultural events, say) from almost any imaginable vantage point. The result may be a very different way of perceiving reality (or at least reality that occurs in a suitably prepared venue).
- Video glasses that place images directly before a viewer's eyes will likely be developed first for entertainment applications but will quickly spread to many other applications.
- E-books will become commonplace.

Rapid development of e-entertainment has already challenged traditional methods for maintaining control of intellectual property. Indeed, one member of the group predicted that the rise of new media will have the effect of revivifying the concept of live performances, since it will become increasingly difficult to protect and therefore to make money on any kind of recorded performance.

Entertainment will also drive development of some key enabling services. (Some members of the group noted that modern streaming media were first developed to support on-line pornography.) The need to sell entertainment in very small packages is likely to generate the first efficient micropayment systems. Systems

that allow customers to search huge numbers of entertainment sources for a particular service or experience may be the precursors of more general dynamic brokerage services. The need to protect intellectual property and expose counterfeit or bootleg entertainment may lead to the development of sophisticated validation systems that will establish the authenticity of specific entertainment products and services. A desire to enjoy entertainment services in private may prompt further development of security protections and "anonymizers."

Within the group, there was also recognition of a dark side to emerging entertainment technologies. New technologies will make it easier for those who are so inclined to consume what many would consider undesirable kinds of entertainment--child pornography, for example. The social dangers inherent in such entertainment may extend beyond its content. Because customers will be reluctant to acknowledge their access to such entertainment, users may fall victim to blackmail. Because dubious entertainment may have to be hidden from information systems managers, viruses may be more easily transmitted. And dangerous, incorrect, or subversive information that is packaged with dubious entertainment will be hard to combat or to refute because it will seldom be out in the public eye.

Supply-Chain Management

The last of the final services discussed by the group was supply-chain management, and control of production processes more generally. The aim of supply-chain management systems is to extend just-in-time concepts of management as far down into the production process as possible and to reduce inventories wherever possible. In today's business climate, one member noted, "a company's assets are really liabilities."

Beyond supply-chain management are more complex information and manufacturing systems that allow highly tailored--almost personalized--production. Indeed, as production management systems evolve, the whole design process will change. Rather than designing products in the hope that customers will like them, the emphasis will be on creating a system within which the customer can truly design his or her own product.

The group noted that some sophisticated supply-chain and production management systems are already in place. The best-known example, perhaps, is Dell Computer. Less well known but equally impressive, according to one member, are the inventory control and stocking processes employed by Walmart. Precise records are kept not only of what inventory remains and how much of

what will need to be ordered, but also of what items are purchased with what other items, the better to arrange the distribution of goods around the store. This member noted that "Every Walmart store manager is a mini-CIO."

The next step, some members hypothesized, will be the creation of information systems that measure performance of an entire production, distribution, and sales process identifying opportunities to increase efficiency. Perhaps the key to such systems will be to devise ways to allow humans to visualize and to understand intuitively the workings of very complex systems.

Good supply-chain and production management systems will drastically reduce the advantages that accrue to cheap labor, possibly ending the flight of manufacturing process to the developing world. This could, of course, have profound consequences for the global distribution of income.

At the request of conference organizers, the group spent some time thinking about the consequences of such systems for agriculture (noting, however, that no one in the group was an expert on agriculture). The group saw great promise in sensing systems linked to GPS receivers that would assess the requirements of very small portions of fields for different amounts of water, fertilizer, pesticides, etc. This information could be transferred to dispensers in tractors moving across the fields and applying precisely measured inputs to exactly the spots in fields where they are needed. The result could be very substantial increases in yields, marked decreases in cost, and reduced pollution due to over-fertilization or runoff. Interestingly, the group believed that the development of such agricultural techniques would probably not widen gaps between rich and poor. They believed that the minimum efficient scale for exploiting these new production technologies could be quite small. Small farmers might therefore benefit. "All you need," one member suggested, "is a sort of expensive tractor."

Of the four final services considered, supply-chain management probably makes the least demands on the enabling services of security, payments, validation, and dynamic brokering. Perhaps this is not surprising since supply-chain management systems are already well advanced, in the absence of most key enabling systems.

Additional Observations

Throughout its discussions, the group repeatedly returned to the notion that distinctions between different final services are eroding and will continue to erode in the future. A fundamentally new distributed information structure containing all key enabling service is evolving, the group believed, and this new

information structure will be common to all final services mediated by IT. The techniques and the characteristics of different final services will become increasing intertwined, with developments in one area quickly being adopted in other areas. The global information structure will be as different twenty years from now as today's information structure is different from what prevailed twenty years ago. Forecasting trends in technology, applications, or their consequences in such a dynamic environment is probably hopeless. Taking issue with the entire premise of the conference, one member suggested that agencies and institutions charged with understanding the consequences of the information revolution should worry less about extrapolating current trends and more about building capability to monitor and to understand developments in real time.

In the course of group discussions, concerns were raised several times about the quality of training many information science professionals are receiving today. Too many students today, members of the panel complained, mistake programming for computer science. "People," they said, "are building information systems today that they don't understand."

Stepping outside its explicit charter, this group speculated about some potentially interesting new information-related artifacts:

- Household implements--dishes, clothes, etc.--may soon be available with built in identifiers that will tell household appliances--the microwave oven, the dishwasher, or the washing machine--how each item is to be treated or processed.
- The group also noted that the price of information storage is falling very rapidly. It will soon be possible, one member suggested, to equip new automobiles with "black-box" recorders that will maintain a record of every aspect of the car's life: every jolt or impact that it has received, the number of hours the engine has run at various speeds, the nature of the roads it has traveled over, servicing that was performed, all manner of diagnostic information, and even input from GPS receivers to record where the car has been. This information could be downloaded remotely to a mechanic who could order necessary replacement parts in advance of the car's arrival for servicing. Noting the downside of vast volumes of detailed information, other group members asked what the consequences might be if such a black box could be subpoenaed in a legal proceeding and then used to reconstruct the activities and the whereabouts of the car and its driver. How many people would want to create a record of so many of their actions?

In commenting on the report of another group, this group was dismissive of backward-looking attempts to characterize the potential market for new technologies and applications. They noted laughable underestimates of the demand for current technologies--Thomas Watson's famous projection that there might be four or five companies in the world that would find they needed a large computer or Alexander Graham Bell's suggestion that telephones might one day become so popular that there would be one in nearly every city in the United States. They noted that demand for new technologies is sometimes more discontinuous and harder to predict than the technologies themselves.

6. Markets

Group Leader: Lily Wu

Rapporteur: Steve Banks

While much of this conference was driven by a technology-push vision of the future, in which technical possibilities are used to forecast future developments, this group focused on economical and social factors that may serve to either constrain those possibilities or to shape them through demand-pull.

Technologists often underestimate how much of supposedly technical trends are actually driven by market or other social forces. An example of this is provided by so-called Moore's Law. While this law is often depicted as the result of physical principles and engineering innovation, much of its character is determined by economics. Thus, delivered CPU chip speeds have increased over the last 2-3 years at a pace that exceeds Moore's Law. Various technical explanations for this have been offered, but the real reason is economic: Intel has always kept a 2-3 year technology backlog, which is taken to market at a rate designed to maximize profitability. This was possible because of their dominant market position. However, three years ago, AMD and Cyrix mounted a significant challenge to Intel's market dominance with new products that quickly captured 25% of the market, resulting in a 50% drop in Intel's stock price. Intel responded to this challenge by bringing technology to market faster than had been its historical practice, successfully meeting the challenge posed by AMD and Cyrix, and as a side effect, beating the rate of increase predicted by Moore's Law.

We are experiencing a major economic cycle in the adoption of widespread information technology analogous to earlier economic transformations such as the industrial revolution. The early stages of such cycles are dominated by the introduction of revolutionary products and services, but the latter stages involve the creation of standardized infrastructures and institutions. Thus, while the events in the early stages of such a transformation may be partially foreseen by thinking through the technological requirements and opportunities, in the latter stages very competitive technologies may fail due to the lock-in effects of

infrastructure created around previously deployed technology. The information revolution may at this time be approximately in mid-cycle. This suggests that while in the past some vision of the future may have been available by thinking about technology, increasingly the future will be determined by markets, standards, and social forces.

Market Criteria

It may be useful, for example, to move from thinking about "what" people want, to "how" they want it. Thus, some important market criteria that can determine the widespread adoption of an artifact or technology are:

- ease of use
- backward compatibility
- enjoyment from use
- low or no cost of ownership
- affordability
- non-critical failures.

Various geographic regions and market segments may vary in their requirements. Important criteria include levels of income (where affordability and cost of ownership may be much more important in emerging economies), extent to which societies or segments are market driven, and the regulatory environment, as the amount of government intervention varies enormously among countries and among segments within a country.

This breakout group envisioned that to determine likely futures, one must take the list of possible or desirable futures being generated by the rest of the workshop and subject them to a screening for market feasibility. Four general classes of filter were discussed:

- whether there is needed supporting infrastructure
- whether there is market demand (or acceptance)
- whether funds adequate for development are likely to be provided
- whether the necessary manpower or talent is available (very critical in developing countries).

Supporting infrastructure needed for product viability includes:

- electrical power
- telephone or other communications
- payment schemes
- protocols and standards
- distribution channels or mechanisms.

Drivers of market demand are:

- ease of use
- affordability
- creation of economic value
- entertainment
- creates knowledge or information
- additional regional criteria (in particular governmental policy or cultural social values).

Funding availability is driven by:

- a clear business proposition
- availability of a robust capital market
- government policy
- intellectual property protection
- venture capital culture
- feasibility of collaborative efforts.

Availability of needed manpower or talent is a function of:

- proper incentives
- education
- immigration policy
- educator availability.

All of the above must be addressed to create a likely future. As mentioned above, they might be thought of as "filters" through which an invention or innovation must pass to be truly successful in having an impact on a society.

Regional Market Drivers and Limiters

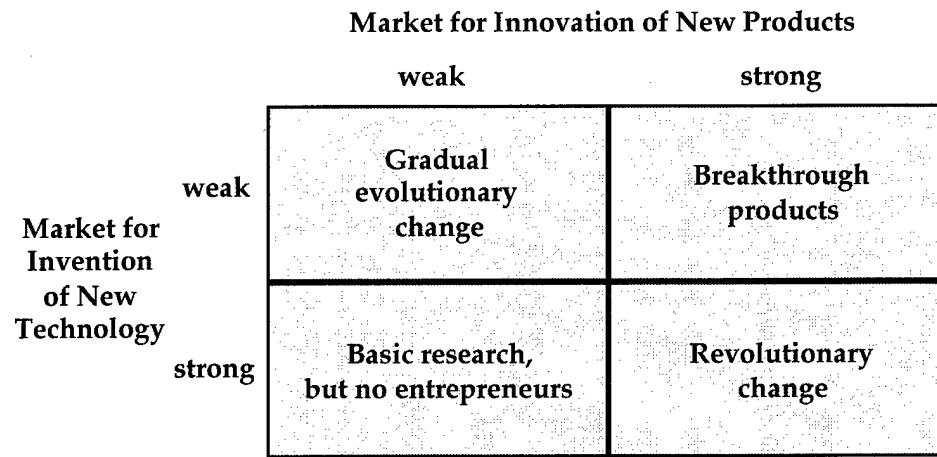
Various of such factors may play varying roles as market criteria in differing regions of the world. The group wrote the following chart as *examples* of market criteria by region, although this is certainly not based on any serious analysis. The intent of this chart (Table 6.1) is as an illustration of the analysis that might be performed by regional and technology experts working together.

Table 6.1: Examples of Possible Regional Market Drivers and Limiters

	Drivers	Limiters
North America	time savings improves health	backward compatibility
Europe	educational value time savings improves health	social concerns; backward compatibility
North Asia	fashion, image educational value	government policy; backward compatibility
Mideast		social concerns
South(East) Asia	creates expertise empowerment educational value	lack of capital, infrastructure, and human expertise
Africa	creates expertise empowerment fulfills basic life needs	lack of capital, infrastructure, and human expertise
Latin America	creates expertise	lack of capital, infrastructure, and human expertise

Technology Life Cycle

There are separate markets for the invention of new technologies and the innovation of new products based on an existing technology. Either of these markets can be strong or weak. The relative state of these two markets dictate where you are in a cycle of innovation, as shown in Fig. 6.1.



**Figure 6.1 – Developments Depend on Separate Markets
for Invention and Innovation**

A technology life cycle begins in the lower left quadrant, where the market for invention of new technology is strong but the market for innovation of products is weak. This is the normal state of affairs when a technology is immature and not ready for productization. However, if the culture has a shortage of entrepreneurs, a cycle of technology development could be stalled there. If a technology shows promise, the next stage would be the lower right quadrant, where the market for both invention and innovation is strong, and in this part of the life cycle, revolutionary changes can occur. Later, as the technology matures, the market for invention can weaken, and while breakthrough products may still be produced, the infrastructure for this technology is consolidating, and the potential for truly revolutionary change is diminishing. Last in a technology life cycle, we arrive at the upper left quadrant, where the market for both innovation and invention becomes weak, and only evolutionary change is permitted.

The diagram in Fig. 6.1 invoked stimulated discussion. The notion of some group members was that basic R&D comes from Ph.Ds rather than from corporate ranks – i.e., that there was a pipeline from the universities to corporations. In the discussion, it was pointed out by other participants that few basic inventions in IT came from universities. That is, “the pipeline doesn’t start at the universities,” as one participant put it. It was mentioned that the “Brooks/Sutherland report” (CSTB, 1995) documents several key technologies and discusses how initiatives shifted back and forth between the “university” and the “corporation.”

Invention of new technologies and innovation of new products are frequently confused, but it is important to distinguish them, as they have different characteristics, and must be promoted in very different ways.

Ken Arrow and others (Alchian, 1958) did a classic analysis of the shortage of engineers and scientists after Sputnik that perhaps needs to be updated to analyze the current set of challenges. (One participant mentioned that recent work by Romer may be relevant in exploring this topic.)

During the plenary discussion that followed this breakout group's report, a participant drew the following figure, linking innovation and invention in a continuing interplay of "cycles."

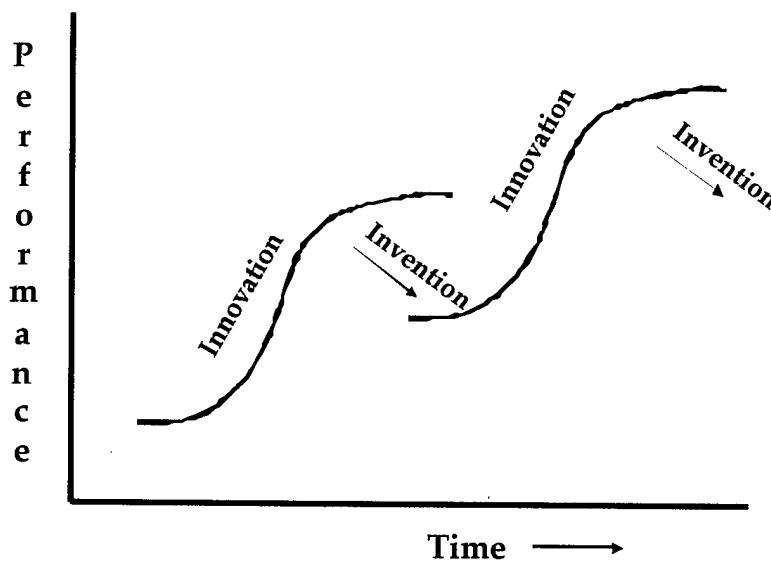


Figure 6.2 – The Interplay of Innovation and Invention Over Time

It might be a useful exercise to elaborate on this diagram for some key IT developments (e.g., wireless communication, wearable computers, \$1 ubiquitous sensors) to see what the time cycles might be and how various innovations stimulate the next cycle of invention and innovation.

7. Beyond Cyberspace

Group Leader: Peter J. Denning

Rapporteur: Tora K. Bikson

Introduction

What will happen when information technology (IT) is ubiquitous--when cyberspace permeates social space? What will society be like when IT becomes part of the background rather than a locus of emerging foreground trends? The charge to this breakout group was to scope and explore the territory beyond cyberspace as we think of it today.

Guiding Themes

First, the group noted that reaching beyond cyberspace probably has to do with grasping for what would usually be thought of in today's time frame as "secondary effects" or "unintended consequences." That is, leading-edge technologies often have what seem like unexpected by-products that later turn out to be major outcomes as these technologies become ubiquitous and converge in varied ways with older technologies.

Next, in the view of the group, such unintended consequences usually have more to do with human practices than with the technologies per se. It is how humans use the technologies that produce the surprises. Further, such surprises can dominate the intended consequences; in fact, they may be independent of or even opposite in effect to the intended outcomes.

Third, the group recognized that both human practices and technologies are contextualized. That is, they are situated in institutional realms (e.g., work, education, leisure) with embedded social norms, legal codes, shared histories, and hosts of more specific mores. These institutional factors are not easily changed and limit the pace and extent of the information revolution.

Domains to Explore

Given the role of institutions in providing the contexts within which human practices interact with and shape the outcomes of new technologies in use, the group decided to organize its Beyond Cyberspace explorations around selected institutional domains within which these outcomes will be manifest. Although a number of promising domains were discussed (including, for example, entertainment, health care, transportation, and other revolutions), the subset of four listed below were chosen for more detailed investigation:

- work
- political process
- education
- crime.

These domains clearly represent permanent--or at least semi-permanent--areas of human concern that will be changed by but will not disappear because of the information revolution. Moreover, each is associated with one or more institutions that involve varied norms, legal codes, situated practices, and so on. Entire professions have been engendered to maintain the functioning of these institutions in society. And each of the domains is susceptible to change and rebuilding by "breakdowns," where old institutionalized structures and behaviors become dysfunctional in the face of new threats or opportunities which they are ill designed to handle and must be replaced. When such sources of breakdown are identified, one participant suggested, it will be worth asking "Who will be winners and who will be losers in the new institutional environment?" As a general rule, the group speculated, when institutions change in response to the information revolution, those who formerly controlled information will turn out to be the new losers.

Among the many questions posed by the conference conveners to breakout groups, therefore, the Beyond Cyberspace group chose to treat possible institutional conflicts, tensions and impediments to the information revolution as an analytic probe for getting at the consequences--both intended and unintended--of ubiquitous IT. For instance, as the group chair noted, "Institutions change slowly. Internet time is fast. This disparity breeds tensions."

Assumptions

The group did not undertake a systematic exercise to identify the key assumptions on which the likely accuracy of its views of the world Beyond Cyberspace would depend (departing from the conveners' charge). However,

from time to time in its deliberations, some recurring assumptions surfaced. Noteworthy among them are the following.

First, it is assumed that knowledge work will constitute an increasing proportion of work in the long term future. This trend is already evident in the developed world; it will continue there and will emerge as well in less developed parts of the world over time.

Second, it is believed that the "first world" will lead the production of IT for the foreseeable future. Again, this is true now and is expected to remain true even if other regions of the world catch up with the developed world in IT consumption.

A third and probably related assumption is that the economy of the first world will not collapse, although moderate fluctuations should not be ruled out.

Finally, although the populations of the developed world are becoming older (a demographic trend already in evidence), an increasing proportion of major decisions affecting the IT industry will be made by youth. "Kids rule," as one participant put it--and he was referring not just to IT consumption but especially to IT production. Young entrepreneurs will continue to compete successfully in the IT marketplace in increasing numbers, particularly as e-commerce lowers entry barriers and as the old top-down large-scale R&D model of successful innovation is replaced by myriad small-scale fast-emerging ventures.

The remainder of this breakout group report summarizes Beyond Cyberspace discussions within the four major domains of interest listed above. Among them, the domain of work received greatest attention.

Work

The lead-off question in this domain--"what/where/when is work?"--generated varied issues that deserved more attention than the group had time to give them. For instance, will work go to where the people are, or will people go where the work is, or both? Such an issue calls attention both to the nature of knowledge work and to roles for migration (physical and virtual) as well as for telecommuting. The group's discussion of this broad arena is presented under four interrelated topic areas below.

The Nature of Work

Manual labor, as noted in the assumptions, is increasingly being transformed into knowledge work. Echoing a viewpoint sounded earlier in the conference,

the group chair suggested that knowledge work could best be construed as work accomplished through systems of communicative exchanges among workers; such systems rely, for example, on the making of requests or offers, the fulfilling of promises, and other elements of performative discourse.

On the one hand, knowledge work is far less easy to observe than physical labor. On the other hand, in IT-based work environments, computer software can be deployed to record and manage the schedule of commitments and completions; they can also measure and track many other work parameters. Workflow systems already carry out such functions in the manufacturing sector and are now emerging in the sphere of knowledge work.

In some organizations, the application of workflow systems to knowledge work has felt like Taylorization and surveillance; and knowledge workers have reacted quite negatively to what they perceive as monitoring and control. In other organizations, by contrast, such technology has appeared to improve the management of knowledge work and to improve the organization's perceived reliability and credibility.

The result probably depends in large measure on how systems for managing knowledge work are implemented. Recent improvements in workflow technology, for instance, are expected to permit such systems to be more user guided (e.g., allowing workers to control or modify the flow of work based on feedback from the workflow system) and more flexible (e.g., offering options for user over-rides of system behavior). In the meantime, according to one participant, "We've turned the Taylor model on its head. Knowledge workers know more than the managers do now, and knowledge workers have so much mobility that they control the viability of the corporation." If so, this result tends to corroborate the view (reported above) that those who formerly controlled information--in this instance, the managers--lose power, relatively speaking, in new IT-based knowledge work environments.

Collaborative Networks

Ubiquitous IT enables knowledge work to be distributed over networks among workers who may or may not be in the same physical environment or even in the same time zone. The advantages potentially yielded by arrangements for any-time any-place work, for instance, or by media that support rapidly (re)configurable teams designed to meet unique task demands, have been well explored in other venues. NSF's "scientific collaboratory" construct is one example; the notion of "e-lance workers" who bid on individual knowledge-work tasks independently of any organizational base is another.

Many knowledge workers today accomplish at least some of their tasks using networks that support shared distributed activity. Getting Beyond Cyberspace in this area would require advances in the ability to componentize both software systems and knowledge-based jobs. Given componentization, it would be possible to issue bids for all kinds of work (including system development work but also any work that could be carried out remotely via a network); the main task left to the corporation itself would be to assemble the results as they came back from bidders. If someone figured out how to do a good job of componentizing software development, for example, jobs could be put out for bids one day and the new systems could be assembled the next day, assuming the components were available "off the shelf." The development of Linux and the calculation of the 9th Fermat number were cited as cases of successful collaborative work carried out by large widely-distributed groups.

Probing the unintended consequences of such an IT-enabled future led to a number of concerns. First, we do not yet know enough about the role of shared tacit knowledge and shared physical artifacts in colocated interdependent work to understand how to create equally viable shared contexts using distributed collaborative networks if this is indeed possible (group opinion was divided). In any case, at present the consequences of attempts to do without actual shared interaction contexts have generally been unpredictable but more negative than positive.

Second, if knowledge work could be parsed into individual tasks to be done on an any-time any-place basis, would the work become meaningless? Would workers become self-absorbed and socially disconnected or disempowered? Could it increase the value of nonmonetary rewards (e.g., peer recognition, or "coolness" earned for individual task virtuosity in software design)? One group member termed this phenomenon "radical individualism," noting it could also be an unintended consequence of moving to ubiquitous individualized distance learning in the education domain.

Third, we know little about the likely skill mix needed to drive and sustain collaborative network-based knowledge work. It might seem a safe bet to say that, at minimum, if such work environments were ubiquitous, there would be a huge and burgeoning demand for IT professionals (who are already in short supply in the United States). But not necessarily, according to one participant who provided an analogy from the 1950s. At that time, given the rate of television diffusion, it would have seemed like a sure thing to predict the need for enormous increases in the number of TV repairmen by the end of the century. However, television technology advances (e.g., getting rid of moving parts, improving fault tolerance, providing diagnostic read-outs for users) essentially

filled that need. The same might be true of the IT field in the future. If so, only a relatively small number of designers and engineers would be needed to push the state of the IT art.

Reorganization of Industries

The fluidity and flexibility of digital tools and objects, together with network-enabled opportunities for disintermediation, are expected to lead to the restructuring of many industry sectors. Two types of restructuring were underscored by the group.

One type stems from advances in networked digital media that will allow many new individuals and groups to become producers in the information economy and to use their own networks of distribution. These effects will be most visible in the near future in such areas as entertainment (e.g., film and music) and publishing (e.g., books, periodicals and news). Currently a small number of companies control most of the content and the delivery of mass media (because of vertical mergers such as the one between AOL and Time-Warner). In the future, disintermediation will enable contents to be provided online by varied producers, including large companies but also small groups and individuals; consumers will be able to select whatever content they prefer at times and places of their own choosing; and control of old delivery channels will no longer be a viable business. Such trends are emerging now in music and film (although progress in film is slower because of the demands it places on display devices). The publishing industry may go the same way.

Group members regard these trends as additional instances of new winners and losers, where those who profited from controlling information in the past end up on the losing side of the equation when IT becomes ubiquitous. There was speculation about the future of mass customization in entertainment and publishing (e.g., Could DirectTV replace Blockbuster? Could broadcasting disappear?). However, concerns were expressed about the potential unexpected consequences of the loss of shared experiences. What, for example, is the value of seeing the same movie? And what is the value of seeing the same movie together? In some ways, these questions parallel those raised about the value of shared actual work contexts above.

A second type of restructuring is predicated on the vision of significant disintermediation leading to the formation of new service brokering industries. In any business sectors characterized by fast-paced network-based transactions between large numbers of providers and customers (including entertainment and publishing but also financial markets, software components and distance

learning), group members foresaw an emerging demand for trust brokers, identity brokers, branding consultants, aggregate brokers (covering whole subsectors, such as cars for sale), and the like. Finally, some dying industries may be resuscitated by global markets becoming widely accessible through pervasive networks (an example is the ability to make local crafts from artisans in less developed parts of the world available for inspection and purchase by customers in other other regions). It was acknowledged that this kind of restructuring of industries was being covered in greater depth by the Services breakout group; however, the Beyond Cyberspace group wanted to note the possibly surprising result that disintermediation generates the need for entirely new classes of intermediaries.

Migration

The discussion of migration was stimulated by one Beyond Cyberspace participant's remark that an unintended consequence of the previous revolution in the nature of work--the industrial revolution--was mass migration, with huge numbers of people moving to different places within and between nations. The information revolution, he argued, is doing the same--Singapore and Ireland, for instance, are massively recruiting bright young people for their IT-intensive industries. Large movements of people, in turn, will undoubtedly change the steady state of the world; but it is unclear what the new steady state of the Beyond Cyberspace world will look like.

In the earlier stages of the industrial revolution in the US, workers moved to where the work was. Later, US industries began to move some of their work offshore to where the workers were (e.g., through direct foreign investment or through outsourcing). Assuming the ubiquity of IT, the potential migration consequences of the information revolution are more complicated to envision because both physical and virtual migration could take place.

So far, the US is in the most favored position to take advantage of physical migration of workers for its IT industry (because of its relatively high quality of life and its well developed, densely interconnected IT structure). On the other hand, it would also be most vulnerable to the negative effects of physical migration (e.g., ethnic polarization). Earlier generations of geographic migrants had to make trade-offs between assimilation of the new culture and the maintenance of national identity, with the direction of the choice contributing either to melting-pot integration or polarization. A globally wired economy, however, might reduce such tensions by allowing individuals to remain in regular contact with their own culture (e.g., through electronic communication

with family members as well as access to media reflecting their own linguistic and social context) while moving to a new country to work. It is unclear whether assimilation would be seriously impaired by such options.

However, for countries interested in avoiding increased ethnic diversity at home, virtual migration might be the preferred future option for acquiring a growing IT workforce. Virtual migration, like outsourcing, could alleviate local tensions between old and new communities as well as resource allocation conflicts created by new demands and extant commitments of community services. It also might be preferred by workers themselves, since they could attain the desired jobs without having to leave their home countries. But virtual migration would not alleviate some significant sources of international tension, such as international resentments created by the virtual drawing off of talent or strains stimulated by increased international interdependencies (e.g., the US could have a direct economic interest in intervening to assure that India and Pakistan avoid war).

Last, group members identified two old issues that may take on new forms in the Beyond Cyberspace world. One focuses on knowledge workers whose rights and benefits in an environment of mobile, distributed, highly individualized yet globally-based tasks might be jeopardized and whose traditional sources of support might be weakened. Questions were raised about the impact of such IT-based revolutions in work on the effectiveness of labor organizers and labor unions as well as the enforceability of desirable codes of workers' rights.

The second old-but-new issue turns on global haves and have-nots. Not every technology is appropriate for every country at any given time. For example, even if the Internet and World Wide Web were ubiquitous today, not every country would be in a position to make effective use of such other high-tech capabilities as high resolution satellite imagery, and therefore may not be able to employ portions of its latent IT workforce interested in that specialty. As a result, its budding GIS specialists or image analysis software developers (or other technically gifted workers) could readily be lured away--virtually or actually--by work in another more developed country's firms, despite the home country's being heavily "wired." Thus the ubiquity of generic networked IT does not guarantee that the digital divide and the tensions associated with it will be overcome. Rather, they may just reappear in different digital arenas of the Beyond Cyberspace world.

Political Processes and Governance

It is critical, one Beyond Cyberspace participant said, to ask how the information revolution will affect political processes. Another group member responded that it would be entirely possible, in the ubiquitous networked IT world of the future, for new "virtual states" to arise that cross national boundaries, use only their own invented currencies, and bypass both national laws and international agreements related to taxation, import/export regulation, fair trade, and so on. Further, given dramatic differences in the pace of change between formally instituted bureaucratic procedures on the one hand and indigenous adaptations of human practices to new technologies on the other, we should expect a tremendous time lag between what actually happens and official changes in governance in response.

These challenging comments ushered in a discussion of the likely state of political processes and governance in the Beyond Cyberspace era. For convenience, the discussion is organized under three main topics below.

National Sovereignty

Beyond Cyberspace participants believe that, for a number of reasons, ubiquitous networked IT is likely to undermine the sovereignty of traditional nation states. For example, national governments will not be able to control information. Further, their grip on taxation will be weakened because people will conduct net-based transactions from the most advantageous sites. Likewise, no nation on its own can protect the intellectual property of its citizens or its corporations. The previously noted internationalization of markets and the fluidity of the labor force (including virtual and actual migration) further contribute to the marginalization of the nation state.

At the same time, transnational entities are emerging with which nation states have to share de facto power. These include large multinational corporations (e.g., telecommunications companies and financial service providers), nongovernmental organizations (e.g., WTO, IMF, The World Bank, WIPO) and intergovernmental organizations or regional alliances (e.g., the European Union, NAFTA). While ubiquitous networked IT provides the foundation for a global economy and a boundaryless labor force, it generates at the same time a demand for transnational bodies within which disputes can be settled, fair practices negotiated, and laws harmonized. Coming to constructive terms with the declining importance of national sovereignty and creating effective transnational

entities will be a major challenge in the not too distant future. The interplay between NGOs and formal national governance will be worth tracking.

Government@Home

It appears that some of the international trends noted above, reflecting a weakened ability to control in areas heavily influenced by IT, are also likely to marginalize the role of government at home. IT-enabled fluidity and fast-paced changes in markets and financial systems (e.g., disintermediated trading, microtransactions) contrast sharply with the pace at which oversight bodies (e.g., the SEC) move. More generally, old rules and procedures are poorly suited to new Beyond Cyberspace business models. Regulatory agencies in particular are especially at risk of not keeping up with these rapid developments.

A second source of marginalization of the role of government at home is reflected in trends toward privatization. Except for core processes of government (e.g., security, law), alternative sources are increasingly being used to provide services formerly administered by government agencies (e.g., transportation, postal service). In a growing number of arenas, government chiefly serves as a transfer agent (moving funds, redistributing wealth); but such functions too could largely be automated and/or outsourced.

On the other hand, following lessons learned by corporate America, government agencies in the US are already attempting to restructure themselves to take better advantages of the capabilities of digital media not only to make internal operations more efficient but also to create direct relationships with their clients and other stakeholders in their business processes. Disintermediation and one-stop network-based access to multiple government services could create performance improvements in the functions they retain. Further, if government agencies learn from the corporate world, they may design their IT-embedded services to provide feedback of the sort that will permit real-time assessment and improvement of ongoing functions. It should also be possible to make varied sorts of government-collected information much more accessible to citizens in the ubiquitously networked nation.

A final question concerned the role of government in innovation. In the past, high-technology R&D was largely the product of government sponsored efforts. At present research laboratories and research institutions with Ph.D-level staffs generating ideas and experiments are being outpaced in IT innovation by small ventures and projects led by relatively junior staff. Given the rate of technological change, very large projects with long lead times are much less viable than large numbers of small experiments that can be rapidly carried out. It is worth asking

what new models of successful innovation will prevail in the Beyond Cyberspace world and what roles, if any, the government should play in engendering or sustaining them.

Electoral Politics

Already in the US there is pressure for "e-voting," and it is bound to become a reality sooner or later.¹⁰ Well within the time frame set out for this exercise the technology will have been perfected to solve authentication problems and prevent fraud and duplication. Beyond Cyberspace participants therefore attempted to probe the potential consequences of any-place any-time voting.

Ubiquitous availability of voting mechanisms would challenge the rationale for representative rather than direct democracy. Online voting is generally favored on grounds that it will enable greater citizen participation in electoral processes. On the other hand, it is not clear that reducing the transaction costs involved in voting would overcome voter apathy; in contrast, some group members suggested that decontextualized e-voting might actually increase apathy. A second concern had to do with volatility. With online voting, there would not be a need to wait two years, for instance, to elect a representative to Congress; it could be done much more frequently. However, reducing the time intervals could result in highly unstable governing bodies.

Similar themes were raised in relation to referenda. That is, e-voting would in principle permit most proposed measures to be approved by the general public; and the latency between proposal and passage (or rejection) of legislation could be vastly reduced. But government is supposed to be slow and measured, according to group members, while the e-voting scenarios envisioned here look like the "death of deliberation." Or, as one participant put it, "direct democracy could be as volatile as the stock market."

On the plus side, ubiquitous networked IT in the service of political processes would enable a complete census to be obtained much more often than every 10 years. Population and labor statistics, for instance, could be tracked in real time. Such procedures would permit significant improvements to be made in the quality of information collected by government to guide national, state and local policy decisions.

¹⁰ A recent primary election in Arizona allowed electronic voting. The precedent has been established, at least in a small, regional election.

Education

The discussion of this domain began with the recognition that there are many interdependencies and feedback loops between education, work, and political processes. As an example, one participant pointed out that substantial numbers of Chinese students go to schools in the US for high-tech education and then remain here as part of the IT workforce; but they are likely to retain close social ties with members of their own culture in the US and at home, potentially influencing political processes in both countries.

It was nonetheless acknowledged that the education domain in the US presents a powerful array of institutional forces resisting transformation--perhaps more so than either work or government. Even given a ubiquitously wired world, Beyond Cyberspace participants were not able to agree on expected major changes or improvements to education or even clearly to delineate critical conflicts and tensions. What follows is an account of the group's deliberations.

Education Technologies and K-12 Education

Although considerable research attention has been given to educational software (for example, intelligent tutoring systems for algebra and geometry and simulated microworlds for discovery learning), very few effective educational software designs have been commercially developed and disseminated. Group members attributed this to the lack of a market-- schools don't have the dollars to spend on large volumes of high quality software, so vendors pursue the business and entertainment markets. Creating educational interfaces to generic software applications (e.g., database systems, GIS systems) surfaced as the path of least resistance to making good educational software accessible in US schools. Another option might be to motivate vendors to improve the instructional content of video games.

Improved interactive systems to support learning comprise a second potentially promising class of educational technologies. Future advances in human-computer interaction incorporating voice and gesture, for example, or high resolution imagery displays on the output side, might yield much more engaging learning experiences. Further, it will be possible to have biofeedback-driven learning technologies. For instance, computer systems can be developed to detect whether the learner is paying attention or whether the learner is grasping the material and to respond accordingly. Since concentrated time on task is the best predictor of learning, these techniques could yield significant improvements in education. Again, however, such technologies have not yet generally been

deployed outside of research contexts; their diffusion to educational settings would depend in part on the capability to produce them in high volume at low cost.

Distance Learning and Post-Secondary Education

Distance learning is already being offered by a growing number of traditional post-secondary educational institutions, although it is currently implemented in the main as a supplement to classroom-based programs. There are at least two noteworthy barriers to its more extensive deployment. One has to do with conflicts over the intellectual property rights to courseware between professors and the institutions in which they are based. Simply put, professors have no incentive to develop high quality courseware if they cannot receive royalties from it (in contrast, for instance, to the textbooks they write). Resolution of conflicts over patents resulting from university laboratory research could provide a model for overcoming this barrier.

A second and possibly more difficult obstacle has to do with the nature of traditional post-secondary education. While knowledge transfer is part of it, a lot of what is learned in school is socialization, achieved through peer group interactions. Distance learners are also at risk of being cut off from the formation of social networks whose value often persists long after the period of formal schooling. For these reasons, distance learning at least in the near term is likely to be most attractive to new demographic segments not previously served by traditional post-secondary educational institutions (e.g., single parents, disabled individuals, older adults, or working adults who would not want to go to a campus to attend classes after a full day at the office), and as a supplement to on-campus courses.

In any case, distance learning is not likely to drive innovative uses of IT in traditional post-secondary education. Rather, IT in these settings will most likely be used for distribution of course materials and provision of digital tools to on-campus learners (e.g., simulations, workbenches).

The Corporate Education Sector

Major IT-based innovations in teaching and learning are most likely to come from the corporate sector in the areas of professional education and life-long learning. The world of work, as suggested earlier, is increasingly a world of knowledge work; and workers will face pressures to keep their knowledge base up to date. Thus the adult education market is growing, as evidenced by the rise

of corporate universities--over 1000 of them belong to the professional society, Corporate Universities XChange.

IT-based techniques are particularly well-suited to the needs of this market for a number of reasons. For instance, participation in traditional classroom-based courses is very costly to employers and employees alike; usually the employer pays course fees but the employee has to take time off from work. Further, IT-based courses can be tailored by learners to suit their own needs (e.g., by stopping and repeating, by skipping over already learned material, by consulting FAQs as needed, by taking trial tests when ready, and so on).

This burgeoning market has already created big pay-offs for the corporate education sector and is beginning to attract competition from traditional universities. Although universities have not been as innovative or as flexible as the corporate sector in their course offerings for adult learners, in the past they had the advantage of being able to offer certification. Now the corporate sector is offering a growing number of certificate programs. One consequence of this competition is the heightened importance of branding (the name of the institution on the certificate). In technical programs, one participant noted, certificates from corporate universities (e.g., Lucent, Sun, Microsoft) sometimes carry more clout than those from similar programs in academic universities. Group members viewed the tension between corporate and academic education providers as a source of positive change.

Education in Developing Countries

Participants in the Beyond Cyberspace group believe that technical advances will yield small inexpensive IT devices that could be distributed on a one-per-child basis to spread appropriate education throughout developing countries. The aim would be to improve literacy and numeracy around the world at primary grade levels. One participant analogized the desired technology to a laptop with speak-and-spell (or speak-and-count) capabilities.

Such tools could enable organizations that are already engaged in assisting international development (e.g., the Peace Corps, UNDP, UNICEF, FAO) more readily to integrate education into their missions. International literacy and numeracy was viewed as the one area in which IT could stimulate major educational transformations within the time frame under discussion.

Crime

In the Beyond Cyberspace world, the domain of crime was seen as having much in common with the domain of business. For instance, it will likely rely on networks of distributed individuals whose activities span national boundaries.

Ubiquitous IT will significantly reduce physical crime for two kinds of reasons. First, cameras, sensors and other surveillance techniques will make physical activity extremely difficult to hide. Second, DNA tracing and other advanced analytic techniques (e.g., gathering physical evidence such as dirt or vegetation particles and analyzing them in relation to samples from a specific geographical location) will make it easier to identify anyone who has committed a physical crime.

An unintended consequence will be the shifting of crime to the IT world, where hiding evidence will be easier for those with considerable technical expertise. In the Beyond Cyberspace world, group members suggested that a new kind of extortion might become commonplace, with ransom being demanded for stolen data (e.g., credit card lists, company proprietary information). Digital retribution might also be on the rise, if disaffected individuals or groups are able to expunge important files, for instance, or generate viruses to avenge perceived wrongs. And new kinds of "insider crime" problems could arise if, because of virtual or actual migration, the IT workforce in US corporations includes large numbers of citizens of other countries.

An upsurge in such IT-enabled crime, in turn, would create new incentives for the development of some kinds of electronic goods and services. For instance, the demand for digital cash (vs. identifiable electronic funds transfers) should increase. Additionally, there should be greater demand for anonymizing services or software that masks or disguises network-based activity.

On the other hand, governments and international bodies would be expected to institute the collection, on a network-wide scale, of many kinds of time-stamped records of activity. In addition, the group envisioned the growth of "cyberforensics"; based on methods for gathering, typing and comparing stylistic elements in program samples, this field would aim to identify perpetrators of IT crime and providers of IT-based criminal services.

The group closed the discussion of this domain by noting that it had succeeded in not making encryption the focal point of its discussion of crime and detection in the information revolution.

8. Some Observations on the Group Reports

**Observers: V. S. Arunachalam,
Charles Herzfeld and Noel MacDonald**

Rapporteur: Richard Hundley

The next session of the conference involved a panel of observers whose purpose was to give their impressions of the breakout group reports, looking for unstated assumptions, clashes, and interactions among the various concepts presented, and addressing questions such as: Does a coherent picture emerge? Where are the conflicts? Compatibilities? Reinforcing trends? Counteracting trends?

The First Observer

The first observer noted that there are three pillars to IT: computers, communications, and content. The world uses these pillars, in various combinations, for three things: command, control, and commerce. Entertainment, socially and culturally derived, is one important component of the commerce application.

The various applications of IT can be treated as either private goods, which are left to the market, or as public goods. The U.S. tends to treat most applications of IT as private goods. Other nations (e.g., India) are treating IT not just as a private good, but also as a public good. They are not leaving it to the "market" to determine what happens regarding IT developments and applications.

As a result of these differences in approach, other nations may/will use IT in different ways than does the U.S. (See further discussion of this point in Section 6, above.)

The Second Observer

The second observer listed a number of topics related to the future course of the information revolution that were missing from or underrepresented in the conference discussions:

- Science fiction ideas regarding the future of the information revolution. He noted that in the past, science fiction writers have often done a better job of predicting the technological future than did the experts in various technology areas.
- The rich-poor gap, which as a result of the information revolution will exist between countries and within countries. (See section 7.)
- New ways of “measuring” software.
- New developments in the input/output coupling of information systems to humans.
- Differing regional impacts of IT, which he believes will be important. (See section 6.)
- The role of the entrepreneur, which he feels was underestimated in the conference discussions.
- The political marginalization of government, which he feels will be a very important issue in many nations. (See section 7.)
- Cultural changes brought about by the use of IT. In his words, kids today are different [than kids when he was a kid] as a result of their use of IT.
- Transformations in the ways of working in many areas (e.g., science) as a result of the use of IT. As one example of this, he mentioned the “cycle time” in the generation of successive versions of scientific papers, which used to be months and now is minutes to days. (See section 7.)

The Third Observer

The third observer highlighted the following additional topics as being important to the future course of IT and the information revolution:

- Bandwidth is a big issue. Bandwidth is fundamental. The bandwidth infrastructure is very important.
- Developments in display technology will be very important.
- Speech translation will be important.

- The bio revolution will be very important, in and of itself, and also in its coupling to IT.
- Microelectromechanical systems (MEMS), nanotechnology, and polymer electronics will be very important.
- Photonics will move very rapidly in the next five years.

9. Concluding Remarks

**Robert H. Anderson, Peter J. Denning,
Richard O. Hundley**

The purpose of the conference reported on here was straightforward: to identify the key developments in information and communication technologies likely to occur over the next 15-20 years, along with the artifacts and services likely to arise out of these developments. The focus was on developments most likely to affect individuals, organizations, countries, regions, and cultures – possibly in a differential manner. By design, the participants were almost exclusively technologists, from industry, academia, non-profit-research organizations, and government. Their focus was on the technology. Feasibility meant to them that a technology could be deployed within a reasonable time at a reasonable cost. They did not attempt to evaluate other meanings of feasibility such as whether a good business case exists for a technology or whether the technology would be socially acceptable. In other words, we did not ask them to explicate in a serious way the *societal effects* that these developments might have. That is a task we leave to social and political scientists, economists, philosophers, and business strategists who are participating at other times in our conference series.

The conference discussions covered a broad range of technology thrusts and generated a rich set of observations regarding artifacts and services likely to occur over the next 15-20 years. Among the many technology, artifact, and service developments postulated, five appear particularly significant due to their broad impact.

Photonics

Optical, multiwave transmission lines and optical amplifiers and switches will make possible all-optical networks with a quantum jump in communications bandwidth, to thousands of gigabits/sec. These transmission speeds, greater than the main memory bus speeds of current workstations, will give rise to major changes in computer architectures, operating systems, and networking protocols. Application software will also change, probably becoming much more

distributed as communications capabilities expand and costs decrease dramatically. Optical signaling will truly be a disruptive technology: disruptive to the computer industry and to the communications industry, potentially as disruptive as the transition from mainframes to microcomputers in the 1970s and 1980s. Many present-day leaders in the computer and communications industries will be threatened with extinction.

Universal Connectivity

The continued explosion in wireless communications, in a variety of forms, will result in anywhere/anytime connectivity -- the ability to connect with anyone on earth at any time of the day or night. This will enable a wide variety of other artifacts and services. It will affect business practices, international financial institutions, and governments.

Ubiquitous Computing

Computers will be everywhere. Small, powerful, inexpensive computers will be part of smart home appliances, smart houses, smart offices, smart buildings, smart automobiles, smart highways, etc., where they will perform a variety of embedded functions. Wearable and implanted computers will be increasingly important aids, also performing a variety of functions.

Computers will be so ubiquitous that we will no longer think of many of them as "computers." They will fade into the background, becoming part of the landscape.

Pervasive Sensors

Sensors will be everywhere as well. Diverse, powerful, inexpensive sensors capable of (limited-distance) wireless communication will increasingly couple the physical world to the cyber world. These will include tiny video cameras, MEMS microphones, accelerometers, gyros, GPS receivers providing location information, smell sensors, food spoilage sensors, biosensors, polymer-based sensors, etc. These sensors will enable a wide variety of new services.

As these sensors increasingly monitor human activities – so that cyberspace-based services may better serve those humans – concerns regarding individual privacy will continue to mount and will demand solutions.

Global Information Utilities

A dream of the designers of 1960s time-sharing systems is about to come true: Over the next 20 years we will be able to plug information appliances into wall sockets in much the same way as we now plug electrical appliances. Just as we obtain electricity, gas, water, and telephone from wires and pipes to our homes, so will we be able to obtain information services.

* * *

These five developments – photonics, universal connectivity, ubiquitous computing, pervasive sensors, and global information utilities – will enable a wide variety of other artifact and service developments over the next 20 years, many of which are discussed in these proceedings and some of which will turn out to have radical impact. When we look back from the vantage point of 2020, we are very likely to find these five developments among the “long poles in the tent” insofar as technology drivers of the information revolution during the period 2000-2020 are concerned.

Invention, Innovation, and Market Forces

All the technology, artifact, and service developments postulated in these proceedings are plausible. Not all of them will occur. Which ones will occur will depend on the manner in which the processes of invention (of new technology) and innovation (of new artifacts and services) play out over the next 20 years. Market forces will have much to say about this.

The conference discussions made a beginning in dealing with such market forces (c.f. Section 6), but only a beginning; much more needs to be said and done. The expected centrality of the five key technologies mentioned above may be more or less predictable, but exactly which artifact and service developments flow successfully from them is not. Market forces will largely determine this – will largely determine the winners and losers over the next 20 years of the information revolution – as they have over the last 20 years.

Although the discussion in Section 6 is only a beginning, it raised several interesting issues. One in particular merits note: Are the organizational loci of invention and innovation underlying the information revolution changing?

- In the 1950s, 1960s, and early 1970s, the bulk of leading-edge IT invention and innovation occurred in universities and large commercial research laboratories, and was carried out (primarily but not entirely) by PhDs driven

by a “scientific” spirit that focused on the generation and propagation of ideas.

- In the 1970s and 1980s, this began to change. University and large-company researchers still played a major role, but an ever increasing share of IT invention and innovation, particularly of new artifacts and services, was occurring in small, often embryonic organizations, and being carried out by non-PhDs – sometimes even college drop-outs¹¹ -- driven by an entrepreneurial spirit that focused on transforming community practices in a relatively short time.

Throughout the 1990s, this change accelerated. Today, the majority of IT innovation flows from smallish (often start-up) entrepreneurial organizations – and not in large, well-established academic or commercial research establishments. And as this change has progressed, market forces have come to play an ever-increasing role at influencing what gets developed and what does not.

The change in the dominant model of innovation has proved to be a contentious issue. How the balance will play out over the next 20 years is anyone’s guess. But the attempts to guess produced lively and sometimes heated exchanges in the breakout sessions. Nevertheless, we will as a field have to come to grips with these changes in the processes of innovation. How this plays out will be fundamental to an understanding of the future course of the information revolution.

¹¹ E.g., Bill Gates.

10. What Comes Next

Project Leader: Richard O. Hundley

As indicated earlier, this conference was the second in a series, as part of a multi-year effort to chart the future worldwide course of the information revolution.

We feel that these two conferences have:

- Outlined in broad terms the major societal trends likely to characterize the information revolution future.¹²
- Developed an initial understanding of the different ways in which this future is likely to play out in various regions of the world.¹³
- Outlined the technology trends likely to drive the information revolution over the next 15-20 years.¹⁴

These two conferences were useful first and second steps. But much more needs to be done. In particular:

- We need to remove the U.S. bias that is almost certainly present in our results thus far, because of the preponderance of U.S. participants at our two conferences, and gain much more of a non-U.S. perspective.¹⁵
- We need to begin to understand the course of the information revolution in Latin America, a region not well covered in the November 1999 conference.
- We need to expose and vet our results before a wider international audience, thereby broadening and deepening our understanding of the way in which the information revolution is progressing in different regions of the world, outside of the U.S.

¹² Reported on in Hundley et al (2000).

¹³ Reported on in Hundley et al (2000).

¹⁴ Reported on in these proceedings.

¹⁵ The November 1999 societal trends conference had about 75% U.S. participants, only 25% non-U.S. participants. The May 2000 technology conference had over 90% U.S. participants.

- We need to develop "country models" of the way in which the information revolution is likely to play out in different nations.

To meet these needs, we currently plan the following:

- A small workshop focused on the future course of the information revolution in Latin America, to be held in Washington, D.C. sometime in the Fall of 2000.
- A major international conference in Europe, sometime in the Spring of 2001, addressing the course of the information revolution throughout all of Europe.
- A similar major international conference in Asia, sometime in the Fall of 2001, addressing the course of the information revolution throughout the entire Asia Pacific region.
- An on-going analytic activity to develop a set of information revolution country models, using the results of our first two conferences as an initial point of departure.¹⁶ These models will grow in breadth and depth as time goes on and new insights are gained (e.g., from the Latin America workshop, the European and Asian conferences, etc.). We anticipate using these models as one of the principal integrating mechanisms for the remainder of this project.

Other activities may well be added to this list as time goes on.

¹⁶ An initial, starter set of such country models was presented in Hundley et al (2000).

Appendix

A. Predicting the Unpredictable: Technology and Society¹⁷

David J. Farber

I have been asked to examine the likely information based technologies that will arrive over the next decade. Note the decade time scale was my limitation since predicting outside that time frame is unlikely to be realistic. For each technology I will discuss what the impact will be on society with particular emphasis on the international aspects. I have chosen to organize this paper as a set of bullets rather than a narrative in the interest of clarity.

Each bullet will be proceeded by a date and a probability. These are my estimates of when the technology will attain large-scale deployment and how confident I feel it will actually achieve that deployment. I will also start with large scale technologies that have major national and international impact and then focus more on technologies that will directly impact the average citizen.

Ultra high speed all optical networks

With the steady progress in the technology that underlies optical networks it is now feasible to predict with some certainty the future directions. Terms like multiwave fiber networks with speeds in the 40-gigabit per wave and number of waves in the 100 range are not beyond the rational dreams of technologists. The inclusion of optical amplifiers makes it feasible even now to remain in the optical domain for continental distances. Current work in all optical switches strongly suggests that we may within the first decade of the 21st century achieve source to destination communications systems in which the signals remain entirely in the optical world. This raises a set of very interesting questions. Some of them are

¹⁷ This is an update of a paper presented at the Max Plank Institute Conference on Global Networks and Local Values, held in Dresden, February 1999. This paper was distributed to participants after the present conference by its author, and is reproduced here with his permission.

technical; some economic and some societal. I will examine each of these in turn. Multi-gigabit speeds have raised a whole new set of very difficult technical issues. Designing and building switching devices and interface devices, which can operate at these speeds, is not simple. It pushes both hardware design and VLSI technology to their limits. As a result, it has been necessary to take innovative architectural approaches to even hope to achieve speeds nearing a gigabit. Perhaps most interesting, though, is the conclusion that many of the ideas developed over the past twenty years in computer architecture, operating system design, and networking protocols seem to be ineffectual when applied to such high speeds. It is worth observing that these communication speeds are of the same order of magnitude as the main memory bus speeds of modern workstations. Thus it is not surprising that we have run into problems. When streams of data arrive at memory speeds, it becomes difficult, given the protocol systems currently in use, to get the data into memory, to allow the processor enough processing bandwidth to examine the data and move it, and still to have processing power left over for other tasks. I will not elaborate in this piece on the solution others and I have proposed for this problem. But basically, the solution revolves around the creation of a geographically dispersed distributed machine, the components of which would be interconnected by high-speed networks. This approach has been well documented.

What is more important than a particular solution is the challenge of facing a future in which gigabit speed networking will be considered slow, in which our communication infrastructure will consist of multi-gigabit, low error, high-latency networks, in which our processing units, while growing faster, will not keep up with increasing communication speeds. It is too easy to just remove a few instructions, hack a few cures, and show that one can operate not too badly at current speeds of communication. Perhaps this is equivalent to saying, "let the next generation solve the problem." I believe that there is a challenge facing the computer communication field of at least the same magnitude as the challenge the field faced in the very early days of networking. Attacking this problem will require the talents of people from every area of both the computer and communications fields--people willing to experiment and willing to face the same set of challenges those in the fifties faced with the then-new computers.

The major impact will be on industry. The changing of technologies forced by these ultra high speed all optical systems will expose existing industrial leaders to the same pressures and dangers that main frame manufacturers of hardware faced in the 70s. Many of them failed to respond to those challenges and several of the then leaders are no longer forces in the computer business. Attempting to continue to market buggy whips in the era of fast cars is a formula for becoming

obsolete. The same is true of software. As the focus shifts from large slow, by future standards, operating systems and individual software applications to the lean and mean systems required by the future high-speed communications, many companies will become obsolete. Applications will tend to become much more distributed as communications capabilities expand and costs, and maybe even price, decrease dramatically. Such changes will upset the current national industrial strengths and will push the need for increased numbers of IT trained people to compete in this New World. Countries which are fast to adopt, have a pool of investment capital and have a pool of flexible trained people will most likely emerge as the leaders.

In the communications space things are much more complicated. When one adds to the all-optical backbone infrastructure the increase in slower speed but still multi-megabit data rate technology capable of delivery to the last kilometer to the home and business, dramatic changes in the communications world becomes possible.

Bits to the Home/SOHO (small office/home office)

Over the past several years, a major change has started in the last kilometer connection area -- the so called local loop/last mile. Prior to that time, the notion was that the last mile was either telephone services or cable TV services. In both cases they were monopoly-regulated services that offered little or no data services beyond what was available via analog modems. While ISDN was in theory deployed, for a number of reasons it failed to be a major player. The reasons were some technical -- ISDN still used the telephone local switch and tended to overload it and some economic -- prices were held high and deployment was sparse. In addition as analog modem technology matured the speed differential between it and ISDN narrowed.

Recently two technologies have become economically and regulatory feasible -- at least in the US. These have been TV cable based data services and the xDSL capabilities over the copper telephone wire. They both offer the potential of always connected multi-megabit two way data services to the home at prices, again in the USA, that are affordable for certainly the SOHO area and many homes.

These create the possibility of providing significant last mile access to the future optical wide area networks. A note: there is the possibility of optical connectivity directly to the home via plastic fiber, etc. However it is not clear that this is feasible economically due to the cost of installation in all but new concentrated

construction. If it is feasible then things are just better and my following argument just gets more interesting.

What will be the impact on the public and industry of this enhanced last mile capability? Again it threatens to attack the business base of several important industries. The most susceptible to economic damage is the telephone industry. The ability to carry telephone traffic over packet switched networks has been amply demonstrated, even though in the current internet the performance is less than standard telephone quality. That differentiation will vanish on future technology internets and even now the capabilities of cable and xDSL strongly suggests that as a local telephone company bypass for at least non local calling, it could be deployed now. Since the capabilities to access these data services will tend to focus initially on the SOHO marketplace, a number of serious impacts suggest themselves.

Perhaps most serious is the draining of the long distance income and even local service fees that will be lost by the removal of the business use. That will most likely force the telephone companies to raise their fees. Such raised fees will impact more strongly on the less advantaged segment of the population. Also in the long run, the telephone industry wedded to circuit switched equipment with long life times will find itself in more and more financial difficulties as more efficient competition arises utilizing much cheaper technology. Since the telephone industry is both a large employer and in many countries a significant source of government monies, it is not at all clear how this will resolve itself. Attempts to preserve the old infrastructures will most likely cause decreased international competitiveness. While the telephone industry is threatened by new technology for the last mile, another threat is arising via wireless systems in the world / city and house.

Wireless and mobility

Wireless technology is one of the fastest growing areas of communications technology. For many years we have been offered the vision of being connected via a digital path at all times. Unfortunately for a long time the technology, regulators and the market place did not combine to deliver the promise. There are several new technologies coming into the marketplace and laboratories that may radically change the wireless world. First, and this is US centric, there are market forces at work that are changing the way wireless is used. The bulk tariffs that are now offered by almost every cellular carrier have changed the balance between the wire world and wireless cellular service. In many cases especially in urban areas the need for a wire line telephone is decreasing. The

costs of wireless with a large allocation of talk time, about 600 to 1000 minutes per month with no toll charges and no roaming bring often the cost of cellular below that of wire service. That will have two effects. One is that again the cream market will be skimmed off the wire telephone service and what is left is the low margin lifeline service and second it will force the costs of conventional toll down to a level to match that of the flat rate cellular -- that is happening already. All this, at least at a nation level, will bring reduced costs and increased capability to the public and the advantages of wireless systems in emergencies, storms, etc.

Internationally life is a good deal more confused. The new GSM is moving along with several competitive systems. The only bright spot in my view is the fact that technology makes it feasible to produce handsets, which are multi-standard, capable. That is they will operate on any of the worldwide standards given of course the licensing authorities within the country allows their operation. The lack of a sensible roaming system makes it much more difficult to live in this environment internationally.

LEO, low earth orbit, systems such as Iridium are coming online and at some time in the future may reach a price point where it will force the rationalization of the normal cellular systems with respect to international roaming. The potential of satellite systems for high speed data is just being explored in the commercial world and one predicts a slow start due to the high initial investment required.

The role of data in the current generation of cellular wireless systems is at best secondary. However proposals for the next generation cell systems talk about data rates that could hit a megabit per second and higher largely due to the small cell size of future systems. In the arena of satellite systems, Hughes and others have been talking about Direct Broadcast systems that allow two way links with modest speed uplinks. Such systems are still not available and it is unknown what the price and performance will be. The use of satellites for multicast applications seems much more desirable than direct point to point usage. Systems under study use such multicasting for Snow Crash-like applications.

Satellites are by their nature transnational and thus raise all the issues of cultural identity, religious rules and national control. These will become ever more of an obstacle to the free exchange of material over networks, be they ground or earth orbit.

Home and personal networks

The wireless world is often focused at mobility in geographic distances such as cities, states etc. The advent of short range very inexpensive radio links such as Bluetooth and equivalent systems.

From <http://www.sss-mag.com/ssnews.html#3>:

Bluetooth technology highlights

- Based upon a small, high performance integrated radio transceiver, each of which is allocated a unique 48-bit address derived from the IEEE 802 standard.
- Operate in the unrestricted 2.45GHz free band, which is available globally although slight variation of location and width of band apply
- Range set at 10m to optimize for target market of mobile and business user
- Gross data rate 1Mbit/s, with second generation plans to increase to 2 Mbit/s
- One-to-one connections allow maximum data transfer rate of 721 kbits/s (3 voice channels)
- Uses packet switching protocol based on frequency hop scheme with 1600 hops/s to enable high performance in noisy radio environments. The entire available frequency spectrum is used with 79 hops of 1Mhz bandwidth, analogous to the IEEE 802.11 standard
- Low power consumption drawing only 0.3mA in standby mode enables maximum performance longevity for battery powered devices. During data transfer the maximum current drain is 30mA. However during pauses or at lower data rates the drain will be lower.

The technology represented by Bluetooth opens up a wide and exciting variety of applications. Essentially everything in a house can now be equipped with network access. Personal devices such as watches and calendars can communicate to other systems in the home and office. An ID card can become an active badge that identifies the user to the environment they are in. Locks can open, lights can come on and temperature can be set to an individual taste when they enter a room. (As a side comment the badge can require a PIN prior to becoming active so as to insure the rightful user is using it.). TV sets can restrict

the program material depending on who is viewing. Thermostats can sense occupants, outside weather, etc., and properly adjust the house saving significant fuel.

More important is the ability for devices to organize themselves into interesting new systems. For example, a PC equipped with a Bluetooth can detect that the PDA (Pilot like personal device) belonging to me (via use of my personal ID card) and update its data base with new appointments etc. The possibilities are huge and will start a new round of innovation at a much more personal level than that of the PC.

As with each of the technologies I have mentioned there is a societal impact. The privacy of the individual will be constantly under attack. If I have an active ID card which constantly announced to all that will listen, or all that will ask, who and where I am, there is an excellent opportunity for massive violations of my privacy. Each of these threats to the individual has a corresponding technical solution and unfortunately the potential for these solutions to be blocked by national laws. For example, most of the applications envisioned by such wireless links would greatly benefit from or require strong encryption. Yet in many nations strong encryption is banned or controlled. Also many nations restrict the export of such technology and thus damage the marketplace for devices with that capability.

Computers

While I have focused my attention in this paper at communications technology since that is the arena where the most change will take place in the next decade, it would be inappropriate to ignore looking at computers and software.

The end of history in computers has often been predicted based on limits of line width, etc., on semiconductor devices. Each decade we predict the end of increased capability due to these effects and each decade it keeps growing. At least for the next 5 years we can expect increased speed and capability out of our microprocessors. Architectures that used to require rooms of equipment are now in a small chip. Further we see yet again the blending of software methodology with hardware architecture as computers that require complex and capable compilers are entering the marketplace. We can expect to see this sophistication increase and begin to see optical interconnects between components to overcome the limits of wire connections. Further we will see increased use of multi-processor architectures to gain increased performance from commodity components as well as increased capability to provide security on the chip. The

limitations on computing, at least at the non-supercomputer end, will come from software.

A major limit to innovation has always been our ability to produce reliable working software. The scale of software systems enabled by the modern computer and communications systems has stressed our abilities to create such systems. This problem started in the 60s and has gotten worse. Further, as such systems have embedded themselves in critical tasks often managing life-supporting systems. This lack of a viable software engineering methodology is currently the major limit to the greater infusion of computers and communications into our society. Numerous attempts to understand the planning and development of large complex software systems have failed to achieve any meaningful success. The USA in its IT² research initiative will devote significant resources in an attempt to solve this problem. However the size and complexity of systems may out race our abilities under the best of circumstances to get software under control.

Repeated failures of key software systems even after the 2000 issues will have societal impact on people and nations. This impact ranges from the loss of credibility on the part of the public for computer based devices with increased pressure not to continue our technologically enables society up to and including massive damage done by nuclear plants and missile control systems which fail.

Some social comments

While I have been asked to address the technical issues and their impact on society, I can not finish this paper without making some social comments. These comments originally were made at a meeting of the AAAS in 1996 and are modified for 1999.

Cyber-rights

John Perry Barlow is credited with having observed that our Bill of Rights is but a local ordinance in Cyberspace. He was referring to the fact that the basic rights which we hold self evident in the USA are only self evident to our society and are not accepted worldwide. Similarly our notions of morality, law, right and wrong are European-centric and are not accepted uniformly worldwide. Our society is individually oriented. The rights of the individual often take priority over the rights of society as a whole. This view is certainly not a world wide view. Asia, especially Singapore, is fond of pointing out that the Asian view puts the group first and the individual is viewed in the light of what is good for the

group. What side will Cyberspace citizens take in this very profound cultural argument? Can both views live compatibly in a closely coupled cyber-world?

In Cyberspace individual national laws and customs, which are often different and contradictory, may conspire to limit the ability of individuals and corporations to freely interchange information, ideas, images and spoken works even when those items are legal and appropriate in the nation of one of the participants. Many societies currently, for example, limit the availability of satellite dishes. Several governments have equated Internet access, along with the fax machine, as the prime vehicles for external disturbances to their control of their society and have stated that in the event of any future internal disturbances they will sever the internet connections rapidly. What will be the impact of such attitudes on international commerce and learning?

The privacy laws that many governments have reasonably instituted to protect their citizens from having their personal information flow outside the control of the laws of their nation raises many difficulties when one is engaged in a Internet environment. The establishment of directory structures which involve some nations' citizens may be in violation of the laws of that nation. Libel laws are traditionally national yet in Cyberspace, libel is instantaneous and globally damaging. Is there a notion of global liability? How do I sue a person in another nation? If I can, do we achieve the lowest common denominator? Is there a global right to privacy? How is it enforced? What happens to global commerce if there is not a common understanding?

Many nations and cultures have dramatically different perceptions of what is proper and not proper for its citizens to possess or to view. Consider an extreme case -- child pornography. We in the United States have strong laws which forbid the distribution, possession etc. of such material -- other cultures may not agree with us or have different notions of the control of such material. Suppose citizens of two such countries send each other such material and the material transits the United States; is stored on a US computer (without the knowledge of the owner of the computer) against the law? Can or should the US intercept such material and delete it, should they arrest the people when they next enter the US, should they close down the computer used to store the material?

Is there an international agreement on the transport of cryptographic material across national boundaries? Is there a right of innocent passage -- that is, it is bound for another nation and just stops for a short stay -- mail relays for example? What is the right of a nation to monitor the contents or addresses of electronic communications that is transiting their nation?

The cyber-economy

As the Internet becomes more a part of the everyday business of the nations, it will become more and more necessary for commerce to take place among the users of the infrastructure. We can expect in a very short period an international electronic marketplace where goods of all types -- merchandise, information, software etc. are being bought and sold.

Historically there has always been a need to create a way of paying for such goods in order to motivate the supply side of the marketplace. Currently our primitive electronic marketplaces have no very effective mechanisms for paying for goods.

This creates an interesting and exciting opportunity to examine just what is needed to supply a mechanism for the exchange of electronic currency and how such a mechanism can exist in a national and international arena.

The issues raised by the potential existence of an international electronic marketplace (IEM) are not limited to just how to pay for things. There is the need to have the equivalent of credit cards, checks and paper money with its various shades of traceability and privacy. There is the need for escrow mechanisms and international exchange etc.

The additional issues raised by the IEM include:

- The use of small payments as the mechanism for enabling the marketing of hypermedia documents where the links are access paths to updated and marketable property. The crossings of the links require the payment of a fee (electronically and capable of allowing very small payments). For example, having accessed the information once if I copy it and give it to a colleague I have lost the ability to search for sub-links and automatic updates.
- Authentication of sellers and buyers when necessary and the protection of that information when required
- Privacy and personal freedom issues as to what I buy and from whom.
- The integration of any such system into the domestic and international banking and funds transfer systems as well as the different laws and regulations of states, countries and needs of law enforcement
- The need to internationalize buyer protection laws.

Cyber-education

Nowhere are the challenges greater than in the possibilities that the Internet offers in education. There is no better way to create international understanding, friendship and exchange than communication and cooperation between schools and students all over the world at all levels. Education applications cover most potential uses of the Internet and impose demanding requirements on the infrastructure. Education is also an area where the public interest is evident.

The role of the universities in educating the citizens who will lead their nations into this future calls upon them to pioneer the exploration of the benefits to be gained as well as the problems to be faced in this new world. Exploration of the Modern Worldwide Multi-Campus University-University of Cyberspace-interacting with lower grade schools and continuing education to provide individual-centered lifelong learning, should therefore be included in the G-7 vision. The intent should be not to just perform experiments with exchange of courses over the network but rather to explore, understand and solve the complicated issues of inter-organizational operation, economics, national laws and tradition that must be solved in order to create such an extended University. Perhaps most important, however, we must understand how such an organization can enrich University life for the students as well as the faculty. The design of the University must address this issue with highest priority if it is to be a success.

A group of Universities strongly believe that the lessons to be learned from this effort will show the way for better understanding of how industry and governments can use the Internet. This effort will contribute to new strategic knowledge necessary to cope with the global structural change of the telecommunications, media and information industries which is expected to lead to an information society. This rapid change calls for extraordinary programs in research and education to provide the competence necessary in government, industry, among users and all parts of society. However, the most important outcome will be to create a new generation of future leaders who have lived and learned in the borderless world of the Internet and who thus will be better prepared to understand and control the structural changes being created by the information society in order to secure fuller more meaningful employment and social welfare for their people.

Appendix

B. Conference Participants

Dr. Robert H. Anderson

Senior Information Scientist and Head, Information Sciences Group
RAND

Dr. Philip Anton

Senior Computer Scientist
RAND

Professor Vallampadugai S. Arunachalam

Engineering & Public Policy Department and Robotics Institute
Carnegie Mellon University

Dr. Steven Banks

Senior Computer Scientist
RAND

Mr. John Baskin

Deputy National Intelligence Officer for Economics and Global Issues
National Intelligence Council

Mr. Jeffrey Benjamin

Senior Associate
Booz Allen & Hamilton

Dr. Tora Bikson

Senior Behavioral Scientist
RAND

Dr. Joel Birnbaum

Chief Scientist
Hewlett-Packard Company

Mr. Maarten Botterman

Research Leader
RAND Europe

Professor William J. Caelli
School Of Data Communications, Faculty of Information Technology
Queensland University Of Technology, Australia

Dr. Jonathan Caulkins
Director, Pittsburgh Office
RAND

Mr. Colin Crook
Senior Fellow, Wharton School
Former Senior Technology Officer, Citibank

Professor Peter Denning
Computer Science Department
George Mason University

Dr. James Dewar
Senior Mathematician and Director, Research Quality Assurance
RAND

Dr. David Farber
Chief Technologist, Federal Communications Commission;
Professor, Univ. of Pennsylvania

Dr. Robert Frederking
Chair, Graduate Programs in Language Technology
Carnegie Mellon University

Professor Erol Gelenbe
Associate Dean of Engineering & Computer Science
University of Central Florida

Dr. Lawrence K. Gershwin
National Intelligence Officer for Science & Technology
National Intelligence Council

Dr. Eugene C. Gritton
Director, Acquisition and Technology Policy Program
RAND

Mr. Eric Harslem
Senior VP of Products and Technology Strategy
Dell Computer Corporation

Mr. Stanley Heady
Executive for Research Alliances
National Security Agency

Dr. Charles M. Herzfeld
Independent consultant

Dr. Richard O. Hundley
Senior Physical Scientist
RAND

Mr. James M. Kearns
Financial Design, Inc.

Dr. Paul Kozemchak
Special Assistant, Intelligence Liaison
Defense Advanced Research Projects Agency

Dr. John T. Kriese
Chief Scientist
Defense Intelligence Agency

Dr. Douglas Lenat
President, CYCORP

Mr. David Marvit
Director, Strategy
Disappearing Inc.

Professor Noel MacDonald
Dept. of Mechanical & Environmental Engineering
University of California at Santa Barbara

Dr. William Mularie
Director, Information Systems Office
Defense Advanced Research Projects Agency

Dr. C. Richard Neu
Senior Economist
RAND

Dr. Edward C. Oliver
Director, Advanced Scientific Computing Research
Department of Energy

Professor Raj Reddy
Herbert A. Simon University Professor
Carnegie Mellon University

Professor William L. Scherlis
School of Computer Science
Carnegie Mellon University

Dr. Enid Schoettle
Special Advisor to the Chairman
National Intelligence Council

Dr. Brian Shaw
Deputy National Intelligence Officer for Science & Technology
National Intelligence Council

Professor Mary Shaw
School of Computer Science
Carnegie Mellon University

Professor Robert Simon
Department of Computer Science
George Mason University

Dr. Stephen L. Squires
Special Assistant for Information Technology
Defense Advance Research Projects Agency

Mr. Phillip Webb
Chief Information Officer
Defence Evaluation and Research Agency, Farnborough
United Kingdom

Ms. Lily Wu
Chief Financial Officer
XLinux Inc.

Mr. Rick E. Yannuzzi
Senior Deputy National Intelligence Officer for Strategic and Nuclear Programs
National Intelligence Council

C. Conference Agenda

Day 1: Wednesday, May 10, 2000

10am-11:30am: Opening plenary <i>(Rapporteur: Tora Bikson)</i>	
Welcome; NIC goals for this activity	Larry Gershwin, NIC
Overview of RAND 3-year project goals and approach	Richard Hundley, RAND
Summary of results of first conference, held Nov 16-19 '99	Richard Hundley, RAND
Objectives, scope and structure of this conference	Peter Denning (GMU) and Robert Anderson (RAND)
Each participant introduces him/herself, gives brief background and interests	[all]

11:30am-11:45am: Break

11:45am-1pm: Plenary on future visions, part 1 Participants give visions of the future up to 2020, with attention to assumptions and claims underlying these visions. <i>(Rapporteur: Steve Bankes)</i>	
Technologies, artifacts, and usage: Some useful distinctions	William Caelli, QUT
Communication networks and technology	David Farber, U Penn and FCC Erol Gelenbe, UCF
Software: Agents, intelligent and otherwise; language and speech translation and interpretation; user interface and multimedia	Douglas Lenat, CYC Robert Frederking, CMU
Group participation, comments	[all]

1pm-1:30pm: Working lunch during next session

1:30pm-3pm: Plenary on future visions, part 2

Participants give visions of the future up to 2020, with attention to assumptions and claims underlying these visions.

(*Rapporteur: Steve Banks*)

Nanotechnology and biotechnology, and their specific relevance to information systems, sensing, and devices; interim findings from Global Trends 2015 study	Philip Anton, RAND
Computing devices and artifacts (PCs, kiosks, handhelds and beyond)	Joel Birnbaum, HP Eric Harslem, Dell
E-commerce and beyond: New forms of doing business, interacting, interrelating in cyberspace	Colin Crook, Wharton James Kearns, Financial Design Inc.
Group participation, comments	[all]

3pm-3:30pm: Break

3:30pm-4:30pm: Panel of observers and discussants

(*Rapporteur: Dick Hundley*)

Panel of observers: Expose and elucidate assumptions that may have gone unstated or unnoticed by speakers. Call attention to clashes among the visions, and discuss whether this may result from differing assumptions.	Peter Denning, GMU Raj Reddy, CMU Richard Neu, RAND Lily Wu, XLinux
Group participation, comments	[all]

4:30pm-6:30pm: Plenary on artifacts and usage, part 1

(*Rapporteur: Dick Neu*)

Active discussion by conference participants on candidate IT artifacts and usage that are likely to become widely used and make a significant difference during the next 20 years. We are interested in systems that are the natural consequence of trends already visible today, and on "wild cards" that could come from nowhere but may be portended by fringe practices today. Consider two categories: (1) those that add to the "great information attractor"; and (2) those that eliminate barriers, thus affecting the differential impact of these technologies. This session should generate a list of candidate artifacts and usages.

(Discussion led by Denning and Anderson.)

7pm: Conference dinner

Day 2: Thursday, May 11, 2000**9am-11am: Breakout groups, part 1**

Four breakout groups are formed. Each considers artifacts (or systems) listed in the final plenary session on the previous day. They formulate positions on the questions:

- What are the realities of today (if any) that make such a system "inevitable"?
- If the system or development is a "wild card", what factors make it something to be taken seriously?
- What are the benefits if the system were to come into wide use?
- What are the downside risks and negative consequences that might result from the system's widespread use?
- What constraints may prevent the system from coming into widespread use? Will they be overcome in the next 20 years?
- What regional differences exist that will influence the use of the technology?
- What key assumptions do you make in formulating this assessment?
- Do any new systems or "wild cards" appear to you as a result of your analysis?

11am-1pm: Plenary – preliminary findings of breakout groups

Each breakout group presents preliminary findings for 15 minutes, followed by group discussion.

1pm-2pm: Lunch

2pm-5pm: Breakout groups, part 2

The four breakout groups reconvene and conclude.

6pm-8pm: Reception at Newell-Simon Atrium, Carnegie Mellon University

Day 3: Friday, May 12, 2000

8:30am-10:30am: Plenary
(Rapporteur: Jim Dewar)

Breakout groups' presentation of findings (30 min. each)

10:30am-10:50am: Break

10:50am-noon: Plenary
(Rapporteur: Dick Hundley)

Panel of observers gives their impressions of the group reports, again looking for unstated assumptions, clashes, and interactions among the concepts. Does a coherent picture emerge? Where are the conflicts? Compatibilities? Reinforcing trends? Counteracting trends? (30 min)

Peter Denning, GMU
V.S. Arunachalam, CMU
Charles Herzfeld
Noel McDonald, UCSB

Group discussion by all participants on conference findings and conclusions

Closing observations and remarks by conference co-chairs and conference sponsors

noon-1:30pm: Lunch (informal discussion)

1:30pm: Conference end

Bibliography

- (Alchian, 1958) A. A. Alchian, K. J. Arrow and W. M. Capron, *An Economic Analysis of the Market for Scientists and Engineers*. RAND RM-2190-RC, 1958.
- (Chambers, 1996) Joseph J. Corn, Brian Horrigan (contributor), Katherine Chambers editor, *Yesterday's Tomorrows: Past Visions of the American Future*, Johns Hopkins University Press, 1996.
- (CSTB, 1995) Computer Science and Telecommunications Board, National Research Council, *Evolving the High Performance Computing and Communications Initiative to Support the Nation's Information Infrastructure*. National Academy Press, Washington DC, 1995.
- (Denning and Metcalfe, 1997) Peter J. Denning and Robert M. Metcalfe, editors, *Beyond Calculation: The Next Fifty Years of Computing*, Springer-Verlag, New York, 1997.
- (Denning, 1999) Peter J. Denning, editor, *Talking Back to the Machine: Computers and Human Aspiration*, Copernicus, Springer-Verlag, New York, 1999.
- (Dreyfus, 1990) Hubert Dreyfus, *Being-In-The-World: A Commentary on Heidegger's Being in Time*, MIT Press, 1990.
- (Drucker, 1989) Peter F. Drucker, *The New Realities*, Harper & Row, 1989.
- (Hundley et al, 2000) Richard O. Hundley, Robert H. Anderson, Tora K. Bikson, James A. Dewar, Jerrold Green, Martin Libicki, and C. Richard Neu, *The Global Course of the Information Revolution: Political, Economic, and Social Consequences: Proceedings of an International Conference*. RAND CF-154-NIC, 2000.
- (Spinoza, Dreyfus, and Flores, 1997) Charles Spinoza, Hubert Dreyfus, and Fernando Flores, *Discovering New Worlds*, MIT Press, 1997.
- (Walter, 1992) Dave Walter, *Today Then: America's Best Minds Look 100 Years into the Future on the Occasion of the 1893 World's Columbian Exposition*, American World Geographic, 1992.